Examination of Trauma in a Neandertal Ulna

By

Diane Marie Eddie

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David W. Frayer, Ph.D.

Chairperson

James H. Mielke, Ph.D.

Douglas L. Nelson, M.D.

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The Thesis Committee for Diane Marie Eddie

certifies that this is the approved version of the following thesis:

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David W. Frayer, Ph.D.

Chairperson

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Abstract

This thesis focuses on the paleopathology of a Neandertal ulna from the site of Krapina (ulna #180). There has been debate as to whether it should be classified as a nonunion fracture or an amputation. To clarify the trauma of ulna #180, its morphology has been analyzed using diagnostic criteria from anthropological and current medical literature, with a focus on a radiological interpretation. In addition, bone specimens from modern humans with known trauma from the Mütter Museum (Philadelphia, PA) are used as comparative evidence. Diagnostic criteria have been created based on the literature and comparative skeletal evidence from the Mütter Museum to determine whether ulna #180 was an amputation or a nonunion fracture. Based on cortical bone thickness, lack of additional bony growth, a smooth rounded cap, no accessibility to the medullary cavity from the site of trauma, and the lack of eburnation, ulna #180 is characteristic of an amputation.

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Chapter I: Neandertals

Neandertals, or *Homo sapiens neanderthalensis*, are an extinct sub-species of modern humans. Neandertals lived during the Middle Pleistocene, approximately between 190,000 to 35,000 years ago (Klein 1999). Studying these extinct relatives allows anthropologists to understand what life was like for our human ancestors. Researchers are able to do this in a variety of ways, including the analysis of archaeological evidence, demographic patterns, osteology, and paleopathology.

Paleopathology allows researchers to access information about the life of an individual because individual paleopathology can document issues relating to development, health, types of injuries, and levels of violence. Anthropologists can use osteological evidence from anatomically modern humans to compare with Neandertal populations to determine differences in paleopathology of both groups and extrapolate what this means about the lives of anatomically modern humans and Neandertals. Trauma is one important aspect of paleopathology, as it allows researchers to understand further details of Neandertal life including the challenges they might have faced.

This section will review and evaluate what is known about Neandertal life and why understanding this sub-species is important in relation to modern humans. In addition, it will discuss the paleopathology of anatomically modern humans, nonhuman primates, and Neandertals, leading to the evaluation of a specific Neandertal bone (ulna #180), with previously unclear paleopathology. Images of the physical specimen, x-rays, and CT scans of this bone were evaluated by the author to assess the kind of trauma experienced and whether the bone represents a healed amputation or a nonunion fracture.

Neandertals lived throughout Europe and in some parts of the Near East in climates ranging from cold and dry with open, tundra environments to temperatures similar to the present; warm forested or patchy environments full of biodiversity (Soffer 2009, El Zaatari *et al.* 2011). Neandertal occupation of a particular region was dependent on the amount of resource diversity available. Regions that contained the most biodiversity had more continuous occupation, whereas regions with less resource availability or resource diversity had settlement patterns which fluctuated, often with changes in the environment (Soffer 2009).

Diet

The traditional paradigm of Neandertal diet asserts that Neandertals were carnivorous with several hypotheses asserting dietary pattern leading to the sub-species' extinction. One such hypothesis suggests that Neandertal nutrition was so poor that it decreased their fertility, which allowed anatomically modern humans to spread across Europe and exploit niches that Neandertals could not (Hockett and Haws, 2005). Another hypothesis further asserts that Neandertals had a narrow subsistence pattern that consisted only of large herbivorous mammals (Kuhn and Stiner, 2006). This interpretation suggests there was no "woman the gatherer" and "man the hunter" for Neandertals, but rather both genders hunted meat and did not forage.

> "With respect to Eurasia, the archaeological record of the Neandertals (the most recent of the "nonmodern" hominins) exhibits little evidence for the kinds of distinct economic roles typically fulfilled by women in recent hunter-gatherer groups. It appears that Neandertal males, females, and juveniles alike participated in a narrow range of economic activities that centered on obtaining large terrestrial game." (Kuhn and Stiner 2006: 953-954)

While this hypothesis acknowledges some diversity in Neandertal diet, Kuhn and Stiner conclude that the Neandertal diet was mainly large mammals, and there was no significant evidence of any other food gathering ability besides hunting. It is proposed that this inability to forage and the lack of a wide diet gave anatomically modern humans an advantage over Neandertals once the large megafauna the Neandertals relied on as their main source of nutrition died

Isotope analysis of bone is a popular method of determining the diet of Paleolithic organisms, including Neandertals and anatomically modern humans. This is done by looking at the relative amounts of two elements, carbon and nitrogen, present and the ratio between these two elements. The a majority of isotope studies for Neandertal diet studies focus on the nitrogen isotope ratio. Nitrogen isotope ratios are used to understand where an organism is located within the food chain.

> "The basis of this pattern is that plants contain nitrogen from the soil or atmosphere, and in Holocene Europe plants generally had ^{15}N values between 0 and 2%. Herbivores that consume plants have body protein (flesh and bone collagen that is 3 to 5% higher than the herbivores (i.e., 3 to 7%). Carnivores that consume those herbivores have bone collagen nitrogen isotope values that are again 3 to 5% higher than the herbivores (i.e., 6 to 12%)… The same process applies in aquatic (freshwater and marine) ecosystems. (Richards and Trinkaus 2009: 16034)

Many different isotope analyses have been conducted on Neandertal specimens. Currently fifteen Neandertals, including two juvenile, have been analyzed. The results of all of these studies showed the same thing: Neandertals were top-level carnivores, with nitrogen levels comparable to contemporary carnivores, whose diet consisted of large herbivorous mammals (Beauval *et al.* 2006, Bocherens *et al.* 2001, Bocherens *et al*. 2005, Bocherens 2009, Fizet *et al.*

1995, Richards *et al.* 2000, Richards and Schmitz 2008, Richards *et al*. 2008, Richards and Trinkaus 2009).

Another method for determining Neandertal subsistence is to analyze the ratio of animal bones found at associated Neandertal sites to the faunal assemblage. One of the most comprehensive studies was conducted by Patou-Mathis (2000). She looked for the presence or absence of particular species and relative abundance of each species at sites that spanned across Neandertal settlements. Major species found at Neandertal sites were horse, mammoth, red deer, bison, ibex, rhinoceros, and reindeer, which are associated with cold and open climates. Patou-Mathis found that most sites were dominated by one major species or by one or two major species, but the type of species varied depending on the location of the site. For most of Eastern Europe, horse was the most abundant resource. Species from all different climate types were found to have been hunted. While there was some variation based on time, climate, and geography, Patou-Mathis' findings assert that a majority of the Neandertal diet across time and space was consistently large to medium sized herbivores.

Several other studies analyzed Neandertal diet through faunal assemblages. One study's findings were similar to that of Patou-Mathis (Daujeard and Moncel 2010). Most sites were usually dominated by one or two major species. Major food sources at these sites were red deer, ibex, aurochs, bovines, horses, and other medium-sized mammals, though the major sources changed from site to site. They suggest, since most of the camps were either seasonal or brief stopover camps, that Neandertals preferentially moved with their food sources. Hoffecker's (2009) review of Neandertal diet in Eastern Europe corresponds with the previously mentioned studies, though he suggests that mammoths and rhinoceros played a more important role in Neandertal diet than previously thought. Gaudzinkski-Windheuser and Roebroeks (2011) focused on faunal assemblages in northwestern and central Europe. Evidence of eating mainly large to medium size herbivores was similar for all areas, but the predominant species exploited varied among sites. Unlike the previous studies, there was evidence of exploitation of small mammals, specifically beavers, at two sites.

Faunal evidence outside of central Europe gives more varied results. There is evidence at Bolomor Cave, in Spain, that birds were processed and cooked, far before the arrival of anatomically modern humans, during Neandertal occupation (Blasco and Fernandez Peris, 2009). This same site also has evidence of tortoise remains that had been processed and consumed (Blasco, 2008). Yet another site in Spain, Bajondillo Cave, has faunal remains of both large and small mammals including aurochs, red deer, goats, and rabbits. Even more intriguing, was evidence that nine different species of marine invertebrates were consumed at this site (Cortez-Sanchez *et al.* 2011).

More recent work requires a revision of this entirely carnivorous perspective. New ways of analysis (e.g., use-wear patterns of lithic remains and dental wear analysis), indicate that Neandertals had a more varied and adaptable diet. One study reports on the dental calculus found in the teeth of three individuals (Henry *et al.* 2010). They discovered all three Neandertals showed evidence of plant consumption. Hardy and Moncel (2011) examined the use-wear analysis on lithic tools associated with Neandertals. These researchers identified striations and residue located on the artifacts that indicated how the tool was used. Based on the artifact analysis they found evidence of processing starchy plants, freshwater fish, and one tool shows evidence of processing birds.

Lev *et al.* (2005) were able to determine that Neandertals ate and utilized plants to some degree at Kebara cave. Using the water flotation method, they were able to retrieve 4205 charred seeds and fruits, 3956 of which they could identify. Based on comparison to modern plant analogs and the prevalence of plant remains, the researchers reached several conclusions. The most important of their conclusions were that Neandertals were engaged in a wide range of plant foraging in the Middle Paleolithic and that Neandertals relied on plant foods during the late Middle Paleolithic. Another study compared the molar wear of Neandertals with early anatomically modern humans contemporary to the Neandertals and modern hunter-gatherer samples (Fiorenze *et al.* 2011). Groups found in northern environments had a more restricted diet mainly consisting of protein from large mammals. However, climates that were more temperate produced a Neandertal diet that contained small mammals, plants, and marine resources.

Another dental study looked at the microwear patterns of molars of 35 Neandertals and compared the patterns of the Neandertals with four recent hunter-gatherer groups (El Zaatari *et al.* 2011). Neandertals from an open environment had similar wear patterns suggesting a diet mainly of meat, with approximately 15% of their diet consisting of plant foods. Neandertals from a mixed environment had a wear pattern that suggested a diet of mainly marine sources, but in which plants formed 36-45% of the diet. Neandertals from a wooded environment had a greater amount of wear than Neandertals found in the other two environments, which indicated a greater amount of plant foods in their diet than the previous two groups. All these studies suggest that Neandertals had a diet more similar to anatomically modern humans living during the later Pleistocene.

Behavioral Modernity: Material Culture and Cognition

Apart from diet, anthropologists have extensively examined the material culture of Neandertals, with evidence suggesting they had a complex material culture similar to modern humans. Neandertals are associated everywhere with Mousterian flake tools. Mousterian flake tools are more complex than tool sets found with previous *Homo* species and require a different, distinctive method of manufacture (Shea and Brooks 2000). The latest Neandertals are also associated with some blade industries more typical the Upper Paleolithic: Szeletian, Châtelperronian, and Aurigancian (Wolpoff 1999). These later blade industries show most of the features required to be classified as modern: the items are even more complex than Mousterian flakes. Stone is not the only material used, bone is also utilized, and items can be purely decorative in nature (Nowell 2010, Peresani *et al.* 2013, Verna and d'Errico 2011, Wolpoff 1999).

Neandertals were behaviorally modern, not just based upon evidence from their material culture, but also from their biology. Neandertals buried their dead, which indicated they had some sort of belief system about death and the hereafter (Wolpoff 1999). They made and wore jewelry, which for many years anthropologists thought was only associated with anatomically modern humans (Caron *et al.* 2011, Peresani 2013, Zilhão *et al.* 2010). There are indications that

Neandertals had symbolic thought and had all of the biological components necessary for speech, implying that Neandertals utilized some form of language. Neandertals had a vowel space similar to modern humans (Boë *et al.* 2002), they had a hyoid bone shaped like anatomically modern humans (Arensburg *et al.* 1989), and had the same allele for the *FOXP2*, a gene connected to language capacity, as modern humans (Frayer *et al.* 2010, Krause *et al.* 2007, Wolpoff *et al.* 2004). As summarized in a recent textbook, "The key point of this discussion of Neandertal characteristics…is that Neandertals likely were not weird humanlike primates, less adaptable and less intelligent than modern humans. The record shows that their behaviors… were similar to modern humans." (Larsen 2011: 381)

Biology

Neandertals and humans have many biological similarities, as seen in the osteological and genetic evidence. Neandertals are not as distinctive morphologically as they are often portrayed. Based on a pairwise analysis of nonmetric traits, Neandertals cannot be considered a distinct species from anatomically modern humans (Wolpoff *et al.* 2004).

> "Neandertal features are not uniformly spread across the Neandertal range, with sharp boundaries with other contemporary populations. Instead, they vary clinally, reducing in frequency to the southeast and east. In the Levant, it has been seriously questioned whether the specimens should be called 'Neandertal' at all because they share few diagnostic features with the Europeans." (Wolpoff *et al.* 2004:529)

European Neandertals are more likely to have certain cranial traits than other contemporary groups: a high nasal angle, a zygomaxiallary suture that turns inward, a maxillary expansion at the lateral nasal borders, and a lateral zygomatic orientation. These traits can be found in modern European populations as well, but in lower frequencies (Roseman *et al.* 2011, Wolpoff *et al.* 2004). Frayer (1992) has reviewed morphological traits that other scholars have asserted to be distinctive to Neandertals. The study compared these traits in Neandertals with other Middle

Paleolithic humans from Africa and the Near East thought to be the ancestors to anatomically modern humans along with anatomically modern humans from Europe spanning from the Upper Paleolithic to Medieval times. Frayer has found that so-called distinctive traits that typify Neandertals were highly variable in the Neandertal species and a persistence of these European Neandertal traits continue on through the anatomically modern humans in the Upper Paleolithic.

Evidence for similarity extends beyond the bones, as discoveries of Neandertal genetics have demonstrated. Neandertals did contribute approximately one to four percent to the autosomal DNA of modern humans in Eurasia (Green *et al.* 2010). This finding suggests interbreeding between modern humans and Neandertals occurred. While this percentage may not seem significant, Hawks (2010) notes any ancestry left in the genetic record has an adaptive value in present-day people and means that any Neandertal genes are important in a selective sense.

Not all genetic evidence finds similarities between Neandertals and anatomically modern humans. Other recent DNA evidence demonstrates that Neandertals are different; the mtDNA between Neandertals and modern humans does not overlap (Serre *et al.* 2004). Hawks (2010) argues the mtDNA variants of Neandertals are gone because these were not as advantageous as more modern variants. There are signs that mtDNA has been selected for in many recent human populations, which may have caused the Neandertal variants to disappear. Neandertals and modern humans share biological, cultural, and possibly behavioral similarities with each other, which is a main reason Neandertals are important in understanding human origins.

Demography

It is difficult for anthropologists to determine the lifestyle patterns of Neandertals because, unlike material culture, osteological evidence, or even genetic data, behavioral clues in the fossil record are rare or have to be inferred. Instead, anthropologists use indirect techniques, including demography or paleopathology. Both demography and paleopathology aid in the interpretation of the context of the osteological evidence. Anthropologists use demography and paleopathology to determine the average size of a Neandertal group, the health of specific individuals, the average lifespan of Neandertals, and whether Neandertals were violent or passive (Caspari 2011, Caspari and Lee 2004, Trinkaus 1995, Underdown 2006).

Demography is used to determine the similarity of Neandertals to modern humans, specifically anthropologists examine mortality patterns, ages, and how the age structure in a Neandertal population compares to modern human populations. Based on the amount of secondary dentin, Caspari (2011) has confirmed that Neandertals from Krapina, the site that ulna #180 comes from, died at a young age compared to modern day standards. Wear seriation pattern analysis of various hominid species' teeth has been conducted and classified individuals as either young adult or old adult (Caspari and Lee 2004). These studies have determined Neandertals from the Middle Paleolithic died young. Both anatomically modern humans and Neandertals from the Middle Paleolithic outside of Europe have longer lifespans than Neandertals from Europe. Longevity increases significantly with the Upper Paleolithic.

Trinkaus' (1995) demography of Neandertals utilized 220 fossil specimens from over 70 different locations and compared Neandertal patterns to 11 modern human samples, a chimpanzee sample, and the demographic data of a bear species living around the same time as

Neandertals. As part of this study, Trinkaus analyzed age patterns and determined Neandertals had a unique mortality pattern. Neandertal mortality increased from infancy into adolescence, which did not fit any modern human pattern. According to Trinkaus, Neandertals had a shortened lifespan, with a large number of young adult individuals present and a small number of Neandertals who live to old age. This high mortality pattern, along with developmental stress found on a number of individuals, implied life was difficult for Neandertals.

Demographic studies have even contributed to hypotheses about why Neandertals became extinct. Sørensen (2011) rejects previous hypotheses about Neandertal extinction based on diet and climate. Sørensen infers that the low fertility rates along with the high death rates, similar to Trinkaus' findings, led to the extinction of Neandertals. The Neandertals met with some unknown, new stress. Sørensen suggests that an infectious disease affected Neandertals, causing an inability to maintain a stable population and thus they became extinct. However, there is no evidence for a 'killer' disease. Most recently, the extinction of Neandertals has been attributed to a massive volcanic eruption (Golovanova *et al.* 2010). This volcanic eruption may have caused massive climate change in the Northern Hemisphere that affected the Neandertals. Neandertal are found within a condensed range when compared to anatomically modern humans, who span across Africa, Asia, and Europe during this period. When the volcanic eruption occurred, many Neandertals and the animals they consumed died, making it harder for Neandertals as a species to survive. This eruption did not affect anatomically modern humans to the degree it did Neandertals due to the wide dispersal of anatomically modern humans.

Neandertals are a behaviorally complex human ancestor and are worthy of study. This project will examine the paleopathology of a single Neandertal ulna. It is important to examine preexisting studies as they will add to the interpretation of the paleopathology in ulna #180. This review allows readers to place the results of this study within the body of literature surrounding Neandertals.

Chapter II: Paleopathology

Paleopathology can provide details about life history and the antiquity of diseases. Paleopathologists study the health of an individual and identify the presence of diseases, trauma, and environmental and genetic effects on the skeleton. These studies often focus on the effects of substandard health in bones and teeth, as they are the two body parts most likely to be preserved after death. Despite this long-term stability, bone is part of a living system; it changes with its environment. Thus, different pathologies affect bone in different ways. For example, bacterial diseases often cause bone to inflame and leave pockmarks on the bone as the infection kills portions of the bone (**Figure 1)**. Malnutrition, which affects development in childhood, leaves Harris lines (growth resumption lines) in the metaphyses in the long bones due to abrupt stops and starts in growth (Aufderheide and Rodriguez-Martin 1998, Ortner 2003). The individual must have a disease for some time for bone to become affected. Most diseases that rapidly kill individuals leave no trace in the bone. In many respects, studying the bony effects of a disease show how a human survived through periods of chronic sickness.

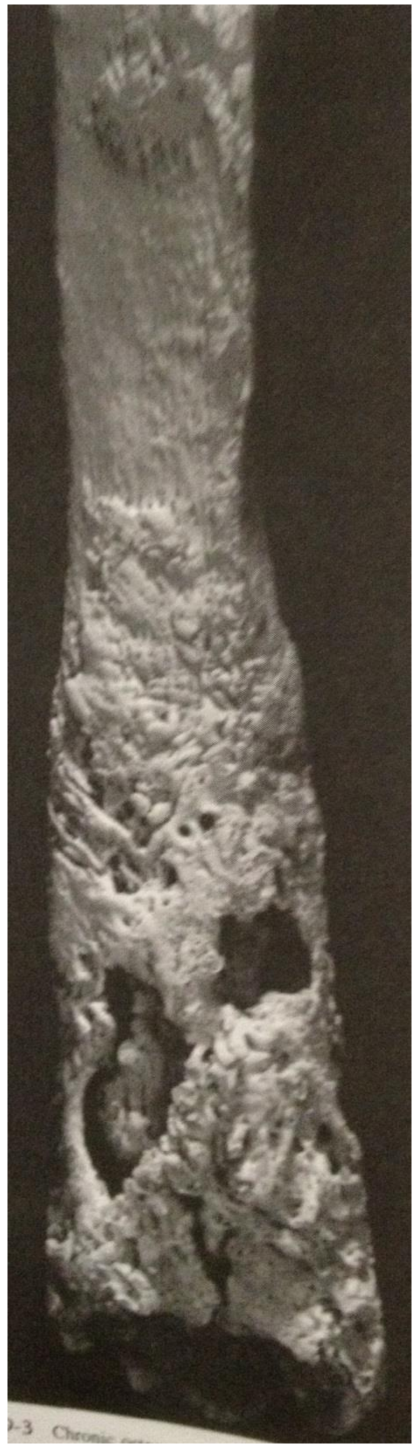

Figure 1: Chronic osteomyelitis case. Note the change in the morphology at the distal end of the bone and the necrosis caused by the infection (Ortner 2003: 184).

Paleopathology in Anatomically Modern Humans

Researchers can determine the cultural activities of a population based on the proportion of specific types of trauma. For instance, a study of fractures in 119 post-colonial individuals from coastal Brazil, found the most common fractures are in the lower limbs (Lessa 2011). Based on the severity, falls or low impact accidents due to traveling from cliffs to the shore likely caused these fractures. Types of fractures found in the paleopathological record also vary depending upon subsistence methods employed by the peoples. Hunter-gatherers who collect food amongst the rocky cliffs by the shores and the group that remained close to the shore for their subsistence had different fracture locations and total number of fractures. Population studies are interested in the niche of the population. The time period, location, type of population (small *versus* larger, rural *versus* urban), and knowledge of major events, such as relationship with nearby groups, and warfare, help anthropologists to understand and interpret how trauma occurs in a population

Knowledge of the time period is important in the interpretation of population-based trauma. Judd (2004) analyzed the proportion of fractures present in the same region at two different time periods, one from the ancient city of Kerma and the other from a modern population living at the same location. While the geographic location is the same for both populations, the patterns found in the two samples are different. The ancient Kerma population was urban; warfare and major social stratification, particularly slavery, occurred in this period. There were two common fracture locations: the cranium and the ulna. Judd interpreted the cranial fractures to be related to assault based on the location on the cranial vault. Cranial fractures can be related to more than just violence, as they can also be caused by accidents based on the context of the injury (Mann and Monge 2006). The location of the ulna fractures, usually at the distal end of the ulna, also known as a parry fracture, are usually caused when an individual uses their arm to protect himself or herself from a frontal assault These types of fractures common in the ancient Kerma group implied some kind of violence in the population. The modern population was rural and there was no warfare during this time. The main locations of fractures in the modern population were on the lower limb bones and the radius, injuries related to a fall. Injuries from prehistoric warfare are different from injuries during times of peace.

Different geographic locations also affected trauma patterns. As with time, location influences the types of injury found in a population. Steyn and her colleagues (2010) looked at the fracture patterns of three modern human populations: one from Crete, one from white South African, and another from black South African. All three came from the same time period, but each had their own distinct trauma pattern. The Cretan population had fractures located in the distal radius (Colles fractures), ribs, and the neck of the femurs, which indicated the trauma was likely due to falls or other accidents. There was no statistically significant difference in the number of fractures between men and women in the Cretan sample. In comparison, the white South African population was more likely to have fractures in the radius and ribs, similar to the Cretans, that were caused by accidents, although there were several blunt force cranial injuries which indicated violence. White South African males were more likely to have fractures than white South African females. Finally, the black South African population came from the Apartheid period in South African history and they had a different fracture pattern from the previous two populations. Black South Africans sustained at least one fracture in their lifetime on the cranium and ulna and have a trauma pattern more like Ancient Kerma, the degree of injuries found on the these two areas indicate violence (Judd 2004, Steyn *et al.* 2010). There was no difference between South African black men and women, indicating the violence was not caused by domestic abuse. Researchers must know both the historical and geographic location of a population to correctly identify the importance and causes of trauma.

Violence and warfare are major factors in the types of paleopathologies found at prehistoric sites. In Bronze Age Portugal similar pathological patterns were found compared to Ancient Kerma and black South Africans. Males were more likely to have fractures than females and the injuries sustained by individuals were indicative of interpersonal violence or defensive wounds. One individual appeared to have been killed due to violent injuries with stabbing wounds found on his cranium, spine, ribs, right leg, left arm, and pelvis and fractures caused by blunt force along his ribs and on his cranium (Jimenez-Brobeil, *et al.* 2012).

Webb (1995) analyzed the paleopathology of Holocene and Late Pleistocene Australian Aborigines to document what health was like for natives before British contact. Pathological conditions in this study were divided into those caused by stress, infectious disease, osteoarthritis, trauma, neoplastic disease and congenital malformations. Fractures were common in Aborigines, particularly in the upper limb. Parry fractures were also found in all Aboriginal groups. Fractures in the upper arm were the most likely area of injury for most Aboriginal groups, except for those individuals excavated from desert locations. The desert sample contained an even number of incidences of trauma between the upper and lower limb, which indicated a more strenuous life style in the desert sample than individuals from coastal areas, according to Webb. Some fractures did not heal properly which resulted in pseudoarthrosis and nonunion (**Figure 2**). Webb analyzed two femurs that appear to have been amputated. In both cases of amputation, the bone was also infected. Webb concluded the amputations were either caused by infection or the infection was a direct result of the amputation (**Figure 3**). While both amputations had a smoothed bony cap, the ends of the amputation were affected by the infection, making these amputations less useful for comparative purposes. It is difficult to determine whether the infection caused the amputation or the amputation caused the infection; the two pathologies compound upon one another.

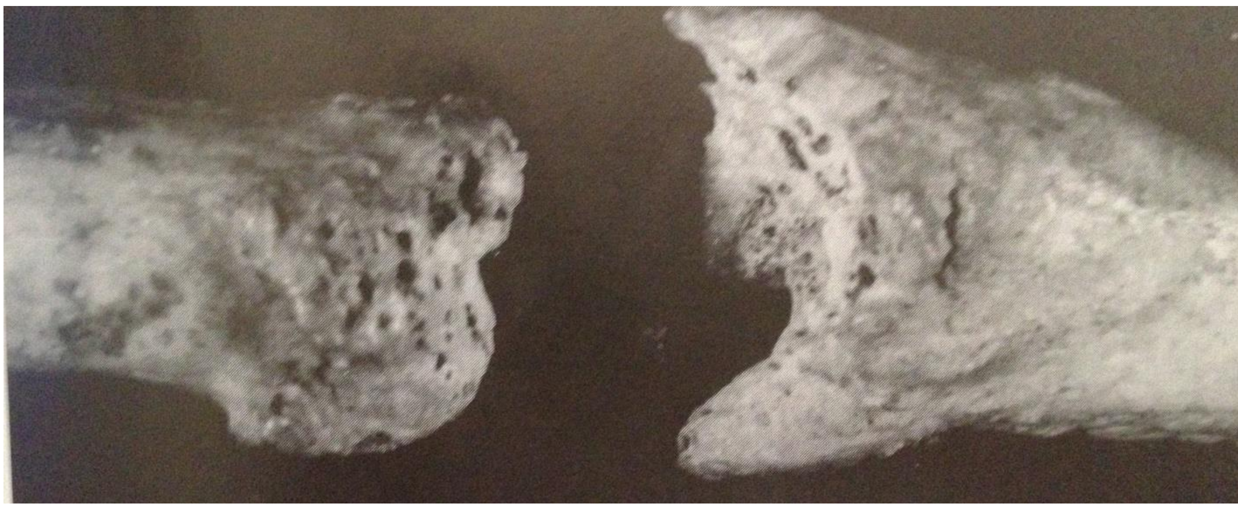

Figure 2: Nonunion fracture (Webb 1995: 199). The two broken bones have formed a pseudojoint. The trauma callus is irregularly shaped and is not smooth.

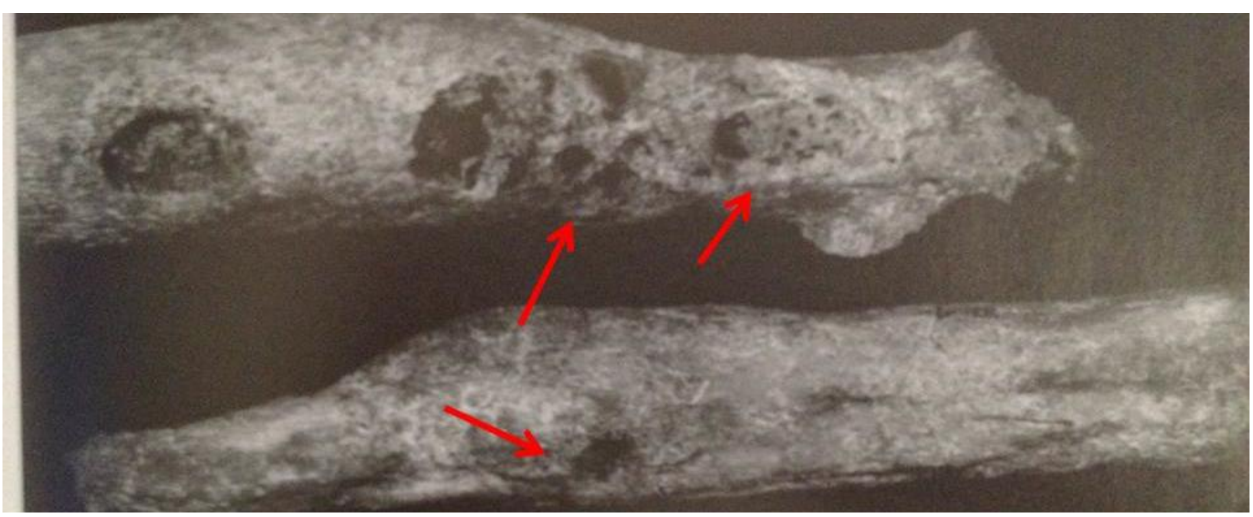

Figure 3: Two femoral amputations (Webb 1995: 213). Both amputations have become infected, which has affected the way the trauma callus has healed similar to Specimen 1268 (discussed in Chapter V), in which the bone has atrophied and the pathology from the infection has affected the pathology of the trauma making it less useful for comparison.

Evidence for amputations used as a form of medical treatment was found in Egypt at the site of Dayr al-Barsha (Dupras *et al.* 2010). Four individuals dated to as far back as 2,686 BC, showed evidence of amputation. Two individuals had bilateral amputations at the metatarsals. The reasons for the amputations were unknown, though both individuals lived after the injury based upon the degree of healing. The trauma calluses had fully healed and the medullary cavity was closed off in each case, though the original bones were shortened. The third individual had an amputated left ulna, probably caused by some sort of trauma. This healing after the trauma had closed off the medullary cavity and the trauma callus was rounded and smooth. This individual also had several fractures to the left clavicle and various ribs and showed signs of hyperostosis and cribra orbitalia, which suggested he had been anemic. The fourth individual sustained a number of injuries during his lifetime. He had fractures in numerous ribs and trauma in the upper right humerus. There were cut marks above the trauma on the right humerus that the authors believe was evidence that the trauma was an amputation. The authors suggested loss of toes for the first two individuals was potentially due to medical treatment, for either leprosy or diabetes. The individual with the amputated ulna was due to trauma. The fourth individual's attempted amputation of the humerus was a potential treatment for previous injuries.

Buquet-Marcon *et al.* (2007) described an injury in a male dating back to at least 7,000 years ago; whom they believe sustained the first amputation in an anatomically modern human currently found in the archaeological record. This individual was well preserved, but was missing his lower left arm and had traumatic alterations in his left humerus, which was their proof this was an amputation. The authors believed this Neolithic individual is unique and may be the first example of assisted amputation. At the Bulgarian site of Tell Yunasite, Zäuner *et al.*

(2011) described a female skeleton dating back to 6,000 years ago, whose right hand was surgically amputated. The radius and ulna of her right hand had fused together. The trauma callus for this injury was smooth and rounded and is indicative of an amputation. Bloom *et al.* (1995) analyzed the 3,600-year-old skeletal remains of an adult male from the Refaim valley in Israel. Like the individual Zäuner *et al.* described; the right radius and ulna appeared to have been amputated as evidenced by the fusion of the two bones resulting in a smooth and round trauma callus. Brothwell and Møller-Christensen (1963a) describe a possible amputation in the right forearm from the IX Dynasty of Egypt. Both the radius and ulna were amputated at the distal end and then fused together by a "bony bridge". A male from 7th century Britain suffered from two amputations (Brothwell and Møller-Christensen 1963b). One amputation was located on the right arm and severed the hand from the wrist. The affected radius and ulna became rounded and eventually united together. The other amputation removed the individual's right foot and had similar rounding on the remaining lower leg. Based on the extent of the bone growth at the area of trauma, the individual survived several years after both traumas. The authors suggest that based on the culture the individual lived in, the likely cause for of amputations was punishment for theft. Mays (1996) describes an individual with an upper extremity amputation. The trauma was diagnosed as an amputation based on the smooth rounded trauma callus. Based on x-rays, the amputated right ulna and radius had a thinner layer of cortical bone when compared to the opposite limb. The subject was a male individual from medieval times in Ipswich, which Mays suggests was likely subject to a violent assault.

Amputations in Non-Human Primates

Amputations found in chimpanzees are usually caused by human created snares and traps. Snares and traps were placed by people with the intention of reducing crop damage; however, Quiatt et. al (2002) fount 18 out of the 55 chimpanzees they surveyed from sites across Africa had some form of digit or limb amputation attributed to an injury from traps. Waller and Reynolds (2001) noted a high prevalence of trauma in the chimpanzee group they observed in Uganda. Eleven out of the 52 chimpanzees sustained limb injuries, only one of which could be attributed to congenital deformation. It was suggested the remaining ten injuries could be attributed to snares and traps set by hunters. The chimpanzees got their hands or feet stuck in a trap and in the process of extracting themselves from the traps permanently injured themselves. Injuries were divided into two different categories: 1) the trap would remove digits, hands, and feet either immediately or they would eventually become necrotic and fall off or 2) the hands and feet would be deformed to the extent that permanently limited mobility, what the researchers describe as “claw-hands”. These chimpanzees survived the loss of a fully functioning hand or foot and were still able to survive in the wild without additional care. Kano (1983) also observed a similar pattern in his study of pygmy chimpanzees in Zaire, with a young male chimpanzee. The male chimpanzee had his right wrist wounded by a trap and was not able to use his hand afterwards. When Kano inquired with local hunters about the occurrence, the hunters noted that injuries caused by traps were not uncommon and normally the portion of the limb distal to the wire trap would necrose and amputate.

Other primates also suffered from traumatic pathology. One study focused on the pathology of the skeletal evidence of African apes found in the Powell-Cotton Museum (Jurmain 1997). One male gorilla had an amputation in the left forearm, distal to the elbow (**Figure 4**). The left humerus had started to atrophy from disuse. The midshaft of the humerus was measured to be 15% less robust when compared to the humerus on the right side. Of the 107 macaque skeletons surveyed by Nakai (2003), only one amputation was found. This amputation occurred in the phalanx of a female macaque. Nakai believed this to be potential evidence of interindividual violence as the injury was indicative of a biting wound. A study of 117 red howler monkeys from Venezuela found two cases of amputation. One amputation caused the shortening of the prehensile tail of a female. The female howler monkey compensated for the loss of the tail by using her hind limbs. The more extreme case of amputation occurred in a female howler monkey in her right arm. This injury was located at the mid-humerus. The loss of an arm had not hindered her, as the female was observed to travel great distances, raise infants, and interact with other howler monkeys for the span of the study (Crockett and Pope 1988).

A study of Darajani baboons found that most individuals who survive to adulthood would have some form of traumatic injury (Bramblett 1968). Most involved fractures occurring in the phalanges of the hands and feet. Bramblett also observed broken ribs, fractures to the pectoral girdle (mainly the clavicle) and vertebrae, fractures in the long bones, particularly the distal portion of the lower limb, and skull injuries, which mainly involved the face. The wide variety of injuries in the baboons suggested that there were many different causes for these injuries. The injuries to the hands, feet, and face were probably caused by violence within groups, while the injuries to the axial skeleton and long bones could be attributed to accidental factors, like falling. The few severe injuries occurred in the palms of the hands and feet and the face. Baboons could survive traumatic injuries, like fractures and even amputations, in one instance. If these severe injuries led to death, it was often a result of infection in the wounds rather than the initial trauma.

Figure 4: Left amputated forearm of gorilla (Jurmain 1997: 8).

Paleopathological Studies in Neandertals

Like modern *Homo sapiens,* Neandertals often had pathologies, specifically trauma, from which researchers are able to extrapolate more about their lives. Neandertal paleopathology studies are similar to modern human paleopathology studies, in that they seek to infer something about a population or describe an exceptional paleopathology case in an individual. However, there is usually an additional element to Neandertal paleopathology studies. Most Neandertal studies analyze how paleopathology in Neandertals relates to anatomically modern humans and what the difference between these two groups implies about Neandertals and modern humans.

Population studies in Neandertals often focus on the paleopathology at specific sites. There are two pathological population studies that focus on the Neandertals found at Krapina, the site where Ulna #180 was excavated. Hutchinson *et al.* (1997) focused on the teeth excavated at Krapina to determine whether there is a developmental difference between Upper Paleolithic modern humans and Middle Paleolithic Neandertals. If there were a dramatic difference in the developmental markers in the teeth, it would imply something about the Krapina Neandertals' lifestyle that restricted their growth. Other anthropologists theorized that the restricted carnivorous diet (Richards *et al.* 2000) caused stress that may have affected growth and development in juvenile Neandertals. If developmental stressors were more prevalent in Neandertals, then these stressors could have contributed to complications in healing from a traumatic injury. The trauma of ulna #180 might take longer than normal or have additional complications (such as nonunion). However based on the analysis provided by Hutchinson and others (1997), Neandertals did not have any significant stress markers based on tooth growth and wear patterns when compared to human samples from the Holocene, so this was not a factor in the healing of ulna #180.

Gardner and Smith (2006) inventoried all the pathologies found at Krapina. Since the sample consisted of 693 disarticulated bones, rather than specific individuals, Gardner and Smith refer to the number of incidences in the collection. The researchers reported five cases of periostitis, suggesting a low number of infections at Krapina. There were only two cases of porotic hyperostosis, which was linked to some type of anemia and/or poor nutrition. There were a number of fibulae with additional growths that indicated a repeated activity, altering the shape of the bone. Other markers of stress caused by physical activity, such as degenerative joint disease and vertebral osteophytosis, were found in the Krapina sample. Several traumatic injuries, including lesions and fractures, are also reported. They discussed ulna #180 and concluded that it was a transverse nonunion, but there was also the possibility it was an amputation.

One of the major goals of Neandertal paleopathological studies is to gather information about lifestyle. Population studies look at the trauma present in Neandertals from different sites to determine such things as diet, presence of fighting, and warfare. According to Berger and Trinkaus (1995), trauma in Neandertal groups is prevalent, with at least one incidence of injury found on almost every Neandertal. Using a sample of Neandertals from several different sites in Europe and the Near East and seven different anatomically modern human samples they compare trauma patterns and analyze how lifestyle affects trauma patterns. They use three prehistoric populations meant to mimic either a hunter-gatherer or early agricultural groups, three modern clinical samples, and an occupational sample of bull riders who worked at rodeos. Neandertals have more injuries in the face and upper arm than the clinical samples or prehistoric samples. Rodeo workers and Neandertals had similar patterns of trauma. This implies Neandertals also interacted in close proximity to large game animals, which causes the same types of trauma. Berger and Trinkaus hypothesize the injuries Neandertals sustain are due to close proximity when Neandertals hunt big game animals. Recently Trinkaus (2012) wrote an article, in which he claimed that the rodeo worker hypothesis needed to be further qualified, if not completely retracted. Trinkaus admitted there were many contributing factors other than close proximity hunting that might have caused the pattern Berger and Trinkaus determined in 1995.

A similar study looked at Neandertal trauma patterns, but used different modern human populations. Underdown (2006) argued that Berger and Trinkaus did not use relevant human samples for comparison. Underdown found that the number of incidences of trauma within Neandertals was more similar to hunting and gathering human populations in Australia. Neandertals did have a slightly higher incidence than some modern populations, but were not significant enough to be outside the normal range of variation. Estabrook and Frayer (2013) analyzed the difference in trauma patterns at Krapina by comparing specific singular elements from a number of different modern human populations. After doing a contingency test between

Krapina trauma and modern human trauma, they conclude that trauma patterns in Krapina are comparable to modern human hunter-gatherer populations, with most cranial and upper limb injuries due to interpersonal violence. This conclusion corresponds more with Underdown's (2006) total population analysis than that of Berger and Trinkaus (1995). In a previous article, Estabrook (2007) suggests there may be regional differences between Neandertals that skew the entire population's trauma pattern based on which samples are included or omitted from total population studies. This finding suggests that Neandertals may not be as representative as previously thought in understanding paleopathology.

Studies of individual Neandertal paleopathologies are much more descriptive in nature. These studies focus on fully describing all possible paleopathologies found in one individual and interpretating the cause or effects of the paleopathology in the individual. Studies on individual Neandertal paleopathologies normally focus on (1) the potential cause of trauma (either *via* hunting or interpersonal violence), (2) paleopathologies common to Neandertals such as DISH (Diffuse Idiopathic Skeletal Hyperostosis), or (3) describing dramatic trauma: specifically fractures (Churchill *et al.* 2009, Trinkaus *et al.* 2008, Trinkaus and Zimmerman 1982, Walker *et al.* 2011, Zollikofer *et al.* 2002).

Focusing on a single individual from Shanidar 1, Trinkaus and Zimmerman (1982) found a potential Neandertal amputation. The right humerus had two areas of trauma; one fracture was located approximately two-thirds of the way down the humerus and the second located on the distal end of the humerus. The right humerus had also lost a large degree of cortical bone making it smaller than the left humerus. However, this may have been due to a nerve disorder, which led to hypertrophy, extreme reduction in muscle and bone, on the right side of the body (Trinkaus 1983). Trinkaus and Zimmerman (1982) originally thought it was an amputation, but after further examination of the rest of the individual, Trinkaus (1983) stated that their interpretations were inconclusive. Causes were narrowed down to an accidental amputation, a nonunion fracture with pseudoarthrosis, or a surgical amputation due to improper healing of a nonunion fracture.

Chapter III: Trauma

In cases where bone receives sufficient force to cause trauma, the bone's original form alters, causing a permanent change to the bone's structure. When studying trauma, scientists determine the external forces that may have damaged the individual. There are five main types of force, and each force interacts with bone in a different manner. Compressive forces squeeze bone, causing bone to shorten in length, but widen in diameter. Tension stretches the bone, increasing length, decreasing diameter, and increasing the fragility of the bone. Angulation occurs when compression and tension are both present. In these instances, major tensile forces bend the bone on one side, with compression forces affecting the other side. If the bone is under too much strain, it will warp in the direction of the major pressure. Shearing, or sliding, force rips tissue apart, pulling the bone in two different directions causing the bone to fracture. Rotational force is a twisting motion coupled with a shearing force. Bending forces twist the bone's original form, while the shearing force tries to break the bone into pieces. Each force alters the bone in a specific direction (Aufderheide and Rodriguez-Martin 1998, Galloway 1999, Ortner 2003). Both the type of force and the type of object that caused the trauma need to be correctly identified to understand what causes a particular injury.

Identification of the type of force, the objects that create the trauma, and the location of the trauma is vital to identifying the correct type of trauma. Researchers classify most types of trauma caused by violence with weapons or surgery as sharp, shearing trauma and then further subdivide trauma by the location of the injury and the type of instrument used. For example, the same type of sharp, shearing force causes both amputation and decapitation; completely removing the bone and the surrounding soft tissue from the rest of the body (Aufderheide and

Rodriguez-Martin 1998). The only difference is the location of the injury; decapitation occurs in the cranium and cervical vertebrae, while amputation occurs in the limbs.

Fractures and dislocations are the most common types of blunt force trauma, with the location of the trauma differentiating the type of trauma. Heavy, dull objects, falls, and repetitive actions all cause blunt force trauma (Galloway 1999). For fractures, the force deforms bone and surrounding soft tissue, but the injured area remains attached to the body. Blunt force trauma causes dislocations to occur near the joints, and fractures almost everywhere else on the body (Ortner 2003). However, classification of trauma becomes increasingly complex, as researchers require detailed characteristics to correctly identify the specific type of trauma (Lovell 1997). If it is possible to determine the type of trauma, then key elements can be identified about an individual, such as cause of death, occupation, and existing health care.

Anthropologists commonly study fracture patterns for two reasons when they analyze trauma. First, this allows researchers to compare differences in fracture patterns between populations in a statistically significant manner. Fractures are common throughout the human archaeological record and found in large numbers, affecting between 5-30% percent of individuals in most populations (Judd 2004, Ortner 2003). In comparison, amputations occur in small numbers in human archaeological record (Aufderheide and Rodriguez-Martin 1998). Secondly, anthropologists examine fracture patterns because they can be classified to a greater degree, as a result of extensive variation and the multitude of levels of the damage. Examples of this detailed classification include the severity of the fracture, whether it completely breaks; the type of force can affect how the bone breaks; and different instruments can cause different fracture patterns (Lovell 1997). Thus, fractures allow anthropologists to compare cross-culturally to find patterns, as well as, identify the specific actions that link to different fractures. Although fractures allow for further classification, there is some disadvantage to this system, as the complexity of designations for fractures often leads to misinterpretation and confusion.

Fracture Classification

There are two major types of fractures: complete and incomplete (or partial) fractures (Galloway 1999). Incomplete fractures do not completely break the bone, whereas complete fractures separate the bone into at least two pieces even though the surrounding soft tissue remains attached to the rest of the body. Forces that build up over a prolonged period causing the bone to warp but not fully break cause incomplete, specifically stress, fractures. Incomplete fractures are caused by stress, mainly by repetitive actions over a long duration of time (Lovell 1997). Complete fractures are caused in a short time, and the bone is separated. A great degree of force or a number of smaller forces from different directions causes the complete breakage of bone (Aufderheide and Rodriguez-Martin 1998, Galloway 1999, Ortner 2003). Researchers further classify complete fractures into several more types based on the way the bone breaks.

Transverse fractures are the simplest type of complete fracture. A direct blow from a force focused on a small area of bone causes transverse fractures (Lovell 1997). The force causes the bone to break into two pieces, as opposed to several. The breakage between the two parts of bone occurs at right angles of each other creating a straight break with no jagged edges (Galloway 1999). Transverse fractures are often associated with accidental injuries, like bracing oneself during a fall (Aufderheide and Rodriguez-Martin 1998, Lovell 1997).

Comminuted fractures are a more complex type of complete fractures. However, unlike transverse fractures, comminuted fractures break into at least three different pieces, usually in a Y or T shaped pattern (Lovell, 1997). Several different forces impacting bone from various directions cause comminuted fractures. The most common types of force are shearing and angulation, and normally a great amount of force causes this type of fracture. There are two types of comminuted fractures: butterfly and complex comminuted. Angulation and shearing forces cause butterfly fractures, with the bone breaking into two large angled pieces and a short piece in the middle (Galloway1999, Ortner 2003). Complex comminuted fractures have more than three pieces. In addition to confusion about the type of fracture, healing fractures can also be confused with other injuries depending on how well the bone heals and the healing stage the bone is in when analyzed.

Proper identification of how bone heals after a fracture is required, as complications related to improper healing can confuse the diagnosis of the original trauma. Based upon how the fracture heals, researchers further classify fractures as union, delayed union, malunion, or nonunion (Lovell, 1997). Union fractures are those in the process of repairing into one single piece of bone or those that have already become one piece. Delayed union fractures repair in the same way union fractures do, but at a slower than expected rate. Malunion factures are fractures that do heal, but leave a noticeable deformity, such as excessive shortening of the bone. Nonunion fractures do not knit together into the original structure (Aufderheide and Rodriguez-Martin 1998, Ortner 2003). Interruptions in the healing process, for instance soft tissue blocking the healing pathway of the two pieces of bone or the bone continually undergoing stress so fragments do not heal, will result in nonunion. Pseudoarthrosis occurs when soft tissue, such as muscle or fat, interrupts the spaces between the separated bones of a fracture, stopping blood from flowing to injured areas and halting the healing process. Nonunion fractures can be confused with amputations in the fossil record, as they both have additional bony growth at the end of the trauma.

Medical researchers have different, more specific terms to define types of fractures, which provide more information about the cause of the fracture. Specific fractures are often named after the individual who first described them or from the action related to the type of break. To correctly classify these specific fractures, researchers must know the specific bone and any other corresponding bones, as well as the location of the fracture, and the type of fracture. Parry, Monteggia, Colles' and Smith's are all fractures that affect areas near the ulna, but they differ based upon the action required to cause the fracture patterns (Galloway 1999).

Fractures of the Ulna

Parry, or nightstick, fractures get their name from the action that causes the fracture, such as the blocking move in stick fighting. Parry fractures are defensive wounds received by individuals trying to shield their faces from an attack. In the effort to protect their faces, the attacked individuals receive a majority of the force on the midshaft to the distal end of the ulna causing a transverse fracture in that region (Galloway 1999, Lovell 1997, Ortner 2003). Another possible fracture type is the Monteggia fracture, which is accidental in nature, but looks similar to a parry fracture (Lovell 1997). Monteggia fractures relate to individuals bracing themselves when they fall backwards, for instance slipping on ice. Monteggia fractures are transverse fractures located at the elbow. The major difference between the Monteggia fracture and the parry fracture is the Monteggia fracture is more proximal than the parry fracture. There are four different types of

Monteggia fractures spanning from the proximal end of the ulna, where the ulna articulates with the elbow, and the midshaft of the ulna (Galloway 1999, Ring et al 1998).

Both Smith and Colles' fractures relate less to this study as they generally only affect the radius (Galloway 1999). Smith's and Colles' fractures can also affect the ulna as well, but this is very rare. Colles' and Smith's fractures usually relate to individuals tripping and falling (Mays 2006). People falling forward onto a hard surface and breaking their fall with their arms are the cause of both Smith's and Colles' fractures. An individual's arms stretching dorsally during a fall cause a Colles' fracture. An individual with their arms stretching outwards but with flexed wrists during a fall causes a Smith's fracture (Galloway 1999).

Amputation

Amputation occurs when a shearing force separates the proximal end of the limb from the distal end. The traumatic forces completely tear both the soft tissue and bone underneath. Unless doctors re-attach the separated portion of the body, the body begins to remodel itself. Shortened muscles find new areas of bone to articulate with, and new muscle attachments remodel the unaffected portion of bone, normally creating a distinct cap or button shape at the end of the shortened bone (Atkins *et al.* 2008, Aufderheide and Rodriguez-Martin 1998, Kirkup 2007). Like a fracture, researchers also use the different causes of an amputation to determine information about the injured individual's life.

Amputation statistics can be found on present day populations. Upper limbs are more likely to be amputated than lower limbs (Statistics on Hand and Limb Loss 2012, Freeland and Psonak 2007). In the United States, there are 1.6 million people who have lost a limb; 34% of these amputations are due to trauma to an upper extremity (Marchessault *et al.* 2011). Approximately 50,000 new amputations occur in the United States each year (Statistics on Hand and Arm Loss, 2012). Based on the rising number of individuals with diabetes mellitus in the United States, it is estimated that the number of individuals living with the loss of a limb will increase to 3.6 million by 2050 (Ziegler-Graham *et al.* 2008).

Occupational amputations differ in the United States from national statistics. Based on estimates from the Bureau of Labor Statistics, 82,903 work-related amputations occurred between 1997 and 2005 (Anderson *et al*. 2010). It is estimated between 16,000 and 21,000 people receive work-related amputations each year (Boyle *et al.* 2000a); 2,633 of these incidents occurred in Washington state from 1997-2005 (Anderson *et al.* 2010). In Illinois, from 2000-2007, 3,984 occupational amputations occurred, more than 80% of which occurred in the fingers (Friedman *et al.* 2012). In Kentucky, 2,297 work-related amputations occurred during 1994-2003 (McCall and Horwitz 2006). Minnesota's number of incidents had only been reported for 1994, with 832 instances of limb loss (Boyle *et al.* 2000b). From these articles, some general patterns emerged for occupationally related limb loss. Males were more likely to suffer from workplace related amputations and these incidents occurred in fields that require the use of heavy machinery. The most likely area of occupational amputation no matter what state was the finger (Anderson *et al.* 2010, Boyle *et al.* 2000, McCall and Horwitz 2006).

Amputation rates and patterns differed among cultures. In Norway, there were 227 incidences of occupationally related limb loss for 2007, 66% of which was located in the upper-extremity (Samant *et al.* 2012). However, reports from 1996 based on the use of prosthetics claimed that there were only 417 individuals in Norway, total, who suffered from the loss based in the upper limb (Østlie *et al.* 2011). Taiwan had a similar pattern of occupation-based amputations to the United States. Between 1999 and 2001, 2,950 cases of work-related limb loss occurred in Taiwan, again mostly in males and a majority of the injuries were based at the finger (Liang *et al.* 2004). Based on information from the National Amputee Statistics Database, there were a total of 4957 new amputations in all of the United Kingdom from 2006-2007. The majority of these upper limb amputations were caused by trauma, due to mechanical, electrical, thermal, or chemical damage, with the remainder of the other amputations were caused by neoplasia, abnormal growth of tissue, or dysvascularity, improper circulation of blood (Information and Statistics Division NHS Scotland 2009). In 1996, analysts surveyed the amputees in Korea to determine general trends in that country. Kim *et al.* (1996) reported amputations occurred twice as much in the lower limb than in the upper limb. This change in trend from the majority of amputations in the upper limb to lower limb was due to the cause of amputations of the Korean sample. Trauma accounted for two-thirds of the individuals surveyed, and the types of trauma affected the lower limb more than the upper limb. The causes of traumatic amputation included the Korean War, the Vietnam War, and increased mechanized traffic with greater speeds and hazards. The second most common cause was peripheral vascular disease, which accounted for 23.5 percent of all amputations. The most common location for peripheral vascular disease amputation was the lower limb.

Amputation Classification

According to Aufderheide and Rodriguez-Martin (1998), amputations rarely occurred in archaeological human populations and, even then, only in fingers and toes as a form of punishment. Amputations can be classified in several different ways. Aufderheide and Rodriguez-Martin (1998) divided amputations into four categories: amputations caused by social justice, amputations caused by accidents and war injuries, amputations caused by deliberate surgery, and ritual amputations. Kirkup (2007) divided the causes of amputations into five different types of amputation that have historically occurred in humans. These types of amputation included 1) dismemberment due to natural causes, 2) accidental amputation, 3) elective (or medical) amputation, 4) ritual and punitive amputation, and 5) amputation caused by weaponry. Mays (1996) only divided amputations into three categories: surgical intervention, judicial punishments, and blade injuries. A different type of object and action caused each type of amputation and there were different levels of intentions behind each category of amputation. Kirkup's (2007) classification system will be used in this study, as it has categories that fit within in a broader range of the human record and does not require certain cultural practices or technologies that both Aufderheide and Rodriguez-Martin's (1998) or Mays' (2006) require.

Dismemberment due to natural causes refers to any disease or health related issues that results in major tissue death. It is not technically an actual amputation, there is not a shearing force involved, but it does result in the loss of a limb and the changes to the body are the same as an amputation. As with amputation, the body reacts to the dismemberment by laying down additional muscle attachments to the unaffected region of the limb, creating a bony cap shortening of bone, and results in the loss of the affected portion of the limb (Kirkup 2007). Examples of dismemberment due to natural causes include congenital absence of a limb, vascular failure, frostbite, and vitamin deficiency. Congenital absence occurs when an individual develops without a part of the limb, usually bone. Vascular failure occurs when blood flow to an area is blocked causing tissue death and loss of a limb. Individuals throughout history could have any of these types of dismemberment. Therefore, the level of technology, or lack thereof, does not affect the presence of dismemberment due to natural causes.

Accidental amputation, also known as auto-amputation, occurs from unintended events, such as a natural disaster, that do not fall into medical or warfare categories of amputation. "It is certain early mankind was liable to accidental injuries by a variety of causes... Tripping when running, falling from heights, being crushed by falling trees or rocks and being savaged by wild animals, produced injuries" (Kirkup 2007: 23). In addition, causes for accidental amputation are present across the archaeological record, including natural disasters and personal hazards (Kirkup 2007). In modern times, car accidents are also a potential cause for accidental amputations (Liang *et al.* 2011). Depending on the type of accident, the limb does not always shear off completely. In extreme situations, the injured individuals must self-amputate. There are several recorded instances of this happening in recent human history, where individuals accidentally received a partial amputation, with a portion of the limb still attached.

Two recent cases in humans demonstrated this event. The first incident occurred in 2001 when a sailor got his hand stuck in a winch during a major storm. His boat capsized while he was still stuck, and he self-amputated to prevent his death (Kirkup 2007). The second recorded incident occurred in 2003, when a rock trapped a climber's hand. The climber waited five days for help to arrive and then, realizing help was not going to come, proceeded to self-amputate his hand and lower forearm (Ralston 2004). Both incidents demonstrated that humans could survive accidental amputations, even though both did not receive medical attention until hours after the amputation.

Medical amputations refer to amputations caused by complications due to health problems, not just the surgical removal of a limb. There are several different types of medical amputations, including improperly healed injuries. In this instance, surgeons remove the injured limb after the original insult. Another type of medical amputation removes part of a limb to remove cancerous, infected, necrotic, or gangrenous tissue attached to the offending limb that would contribute to worsening health or death (Kumar *et al.* 2011, Kirkup 2007). Medical amputations can also include amputations caused by improper medical practices. This includes misapplied bandages or tourniquets, which cuts off the blood flow to the limb resulting in tissue death (Dupras *et al.* 2010, Kirkup 2007). In all cases, health problems initiated the loss of a limb.

Ritual amputations are religious, punitive, or legal in nature. They are intentional; ritual amputations are not caused by warfare or weaponry and are performed in accordance with deeper symbolic meaning for legal or religious purposes. Ritual amputation usually occurs in the smaller digits of the fingers and toes. Ritual amputations can be found in the archaeolgical record starting in 5,000 BC and some instances continued as recently as 2005 (Kirkup 2007). Ritual amputation can symbolically mean a variety of things including, but not limited to, legal punishment for theft, mourning of a dead relative, or remorse for an unpaid debt, (Aufderheide and Rodriguez-Martin 1998, Kirkup 2007). Ritual amputations are done as a symbolic act, rather than for life saving or health purposes unlike the previous types of amputation.

There is one final type of amputation: amputation due to warfare or weaponry. The major characteristic for amputations caused by warfare is fighting with weaponry that causes the amputation. Swords, guns, and large artillery (any metal weapon) all cause warfare amputations. Archaeological evidence from a site dated to 1385, in Portugal shows a probable amputated right humerus caused by a sword wound (Cunha and Silva 1997). Amputation can also occur as a part of trophy taking after warfare has ended (Andrushko *et al.* 2010). Amputations caused by warfare increases with the invention of the gun in the fifteenth century, where the initial injury caused by the weapon is no longer the only potential cause for amputation. Shrapnel, pieces of the projectile, and bits of clothing embedded in the tissue by the projectile may cause tissue death or infection, requiring a medical amputation (Kirkup 2007). Amputations caused by warfare become extremely prevalent with projectile weapons.

Chapter IV: Methods and Materials

There are two aims of this study. Using radiographs and photographs, the first goal is to accurately describe the trauma sustained by ulna #180.. The second aim is to develop a set of diagnostic criteria to determine whether ulna #180 is a nonunion fracture or an amputation.

Ulna #180

Ulna #180 comes from the archaeological site of Krapina. This Croatian site was first excavated in 1899 (Radovčić 1988). Krapina contains material and fossil evidence of human ancestors who lived during Marine Isotope Stage 5e, approximately 130,000 years ago (Rink *et al.* 1995). The fossil evidence from this site contains 874 different specimens. However, these specimens are disarticulated and could represent 80 different individuals, though it is more likely to represent fewer (Kricun 1999, Radovčić 1988).

Ulna #180 is housed at the Croatian Natural History Museum in Zagreb, Croatia. Rather than collecting data from the specimen itself, this study examined notes, photographs, and radiographs provided by D. Frayer (Lawrence), scans from J. Radovčić, (Zagreb), and additional images by L. Bondioli (Rome).

Classification of the specimen

Intrepretation of the radiology sources is based upon methodolgy described in "Chapter Four: Diagnostic Paleoradiology for Paleopathologists" of *Paleoradiology: Imaging Mummies and Fossils* (Chhem and Brothwell 2008). This text outlines several sets of diagnostic criteria for describing radiological specimens (**Table 1**), lesions within these specimens, and factors that may affect intrepretation of an archaeological specimen . According to the authors of this text, x-ray is the optimal tool for examining a specimen, allowing for a thourough study of the necessary criteria used to determine the classifiction of trauma. They suggest that CT is only needed to clarify changes already seen via x-ray. Although this text is useful for establishing a protocol for classification of specimens, it does not provide detailed criteria on how to differentiate between an amputation and a nonunion fracture. Therefore, a further more specific protocol is needed.

Table 1 The paleoradiological method of diagnosis (Chhem and Brothwell 2008: 75)
1. Obtain the best x-ray of the specimen
2. Identify the lesion
3. Analyze systematically the basic x-ray patterns of the lesion
4. Combine the relevant basic x-ray patterns
5. Determine if the x-ray is a normail anatomical variant
6. Determine if the x-ray abnormality is the result of taphonomic alteration
7. Discuss the differential diagnosis
8. Always discuss pseudopathology
9. Suggest final diagnosis from the broad category of bone and joint diseases

Determining diagnostic criteria

Several paleopathology and radiology references have suggestions on how to differentiate between a nonunion fracture and an amputation, which are listed in the subsequent sections. However, previous methodologies of diagnostic criteria can be contradictory and vague. Evidence, in the form of personal notes, sketches, photographs, and thickness ratios, was collected from the Mütter Museum in Philadelphia, Pennsylvania, from five specimens with known amputations or nonunion fractures. The comparative data from the Mütter Museum, in conjunction with current literature, was used to determine useful criteria upon which to judge ulna #180.

Buikstra and Ubelaker (1994) devote a chapter to creating a uniform method of differential diagnosis for all paleopathology in *Standards for Data Collection from Human Skeletal Remains*. This text divides paleopathology into eight major categories. The fifth category relates to fractures and dislocations, which also includes amputations (**Table 2**). However, the section regarding differential diagnosis of amputation is limited. "Amputations (5.2.8) are identified by a missing segment, indications of healing, and evidence of bone loss." (Buikstra and Ubelaker 1994: 120). The criterion for nonunion fractures was similarly vague, as nonunion fractures were diagnosed solely because of existing pseudoarthrosis (**Figure 5**). In addition, the text fails to fully describe what the authors consider to be pseudarthrosis.

Figure 5: Example of pseudarthrosis, the authors included a picture of a known nonunion fracture of a left radius (Buikstra and Ubelaker 1994: 148).

Table 2: 5.0.0 Fractures and Dislocations (Buikstra and Ubelaker 1994: 115)

5.1.0 Type of fracture (indicate all)
5.1.1 Complete
5.1.2 Partial (greenstick)
5.1.3 Simple
5.1.4 Comminuted
5.1.5 Spiral
5.1.6 Compression
5.1.7 Depressed, outer table only
5.1.8 Depressed outer and inner tables
5.1.9 Pathological
5.2.0 Shape characteristics (indicate all)
5.2.1 Blunt round
5.2.2 Blunt oval
5.2.3 Edged (bladed)
5.2.4 Projectile entry
5.2.5 Projectile exit
5.2.6 Projectile embedded
5.2.7 Radiating
5.2.8 Amputation
5.3.0 Perimortem fracture (no observable remodeling)
5.3.1 Clearly the result of perimortem trauma
5.3.2 Ambiguous, possibly postmortem trauma
5.4.0 Fracture sequalae (indicate all)
5.4.1 Callus formation, woven bone only
5.4.2 Callus formation, sclerotic reaction
5.4.3 Healing obliteration of cranial fracture
5.4.4 Nonunion
5.4.5 Tissue necrosis
5.4.6 Infection
5.4.7 Traumatic arthritis
5.4.8. Joint fusion
5.4.9 Traumatic myositis ossificans

Buikstra and Ubelaker (1994) is not the only source that lacks a complete methodology for diagnosis. Several sources briefly discuss or include only incomplete criteria for differentiating between nonunion fractures and amputations. Waldron (2009) warns that paleopathological misdiagnosis is common and can easily happen if the investigator is not careful. This appears to be particularly true when distinguishing between an amputation and a nonunion fracture, as diagnostic books (e.g., Ortner 2003) advise that it is difficult to discern between the two. For identifying amputations, Steinbock (1976) describes how amputations heal, writing "...Endosteal callus forms after about two weeks to narrow the exposed end of the cavity. After several weeks to months, the endosteal callus forms a cap over the medullary cavity. A complete bony cap is not always produced, but in all cases there is a rounding and smoothing of the stump." (Steinbock 1976:36) Medical texts on callus formation after amputation also note the closing of the medullary cavity and the smoothing of the trauma callus (Barber 1929).

In the second edition of <u>Identification of Pathological Conditions in Human Skeletal Remains,</u> Ortner (2003) discusses the misdiagnosis of nonunion fractures and amputations, particularly in the distal forearm and leg. He suggests, just because there is a lack of a distal portion of the bone, this fact does not provide evidence of an amputation, which is a direct contradiction to Steinbeck's (1976) diagnostic view. Ortner does not describe characteristics of amputations in this volume; however, he provides a description of a typical example of pseudarthrosis. "... [T]he ends of the broken bone are joined by connective tissue and, indeed, extensive callus may form... With time the broken ends of the bone will be sealed off by new bone formation... A joint capsule may surround the joint space." (Ortner 2003:131) Aufderheide and Rodriguez-Martin (1998) note that pseudarthrosis is normally associated with the formation of a false joint.

The authors add that in cases of pseudarthrosis the fracture ends become rounded as the medullary cavity hardens. The sclerosis of the medullary cavity is responsible for the further lack of healing.

Comparative Evidence

In addition to data from the literature, comparative evidence was also collected from the Mütter Museum in Philadelphia, Pennsylvania, for the purpose of diagnostic comparison. The Mütter Museum is a medical history museum, which holds specimens with pathologies of interest. The collection houses five human long bone specimens with a known diagnosis of amputation or nonunion fracture, which were used to derive notes, sketches, photographs, and thickness ratios (**Table 3**). Comparison of these samples to ulna #180 will be fully discussed in the following chapter. This primary evidence along with data provided in the literature is useful in determining diagnostic criteria necessary for classification of ulna #180.

Table 3: Specimens Examined from the Mütter Museum and Their Pathologies

Specimen	Bone Classification	Pathology of interest
1427.52	Tibia and fibula	Nonunion fracture
1409.05	Femur	Amputation
1268	Humerus	Amputation
1454.10	Tibia	Amputation
1454.50	Tibia and fibula	Amputation

Chapter V: Results

Initial Description of Ulna #180

Before classifying the type of specific trauma, a description was performed as per *Paleoradiology* (Chhem and Brothwell 2008). Initial examination based on photographs provided by D. Frayer (**Figure 6)** determined there are no pockmarks on the bone, and the bone is not materially malformed, which would imply some sort of genetic or environmental disorder. In addition, there are no Harris lines present, which would imply a lack of nutritional distress in childhood. The bone was not infected; unlike other specimens reviewed, see Mütter Museum specimens in a later section. There are signs of postmortem erosion (or breakage) at the proximal end of the ulna, which can be attributed to taphonomical processes. The distal end is intact without taphonomic alteration. The major paleopathology of ulna #180 is a shortening of the bone with an additional bony cap, suggesting traumatic force abruptly broke the bone after it had fully developed.

Figure 6: Full view of ulna #180. Picture provided by D. Frayer. The blue arrow indicates the area of postmortem taphonomy at the proximal end. The red arrow highlights the pathology of interest. A callus has formed after some form of traumatic injury.

The author has identified several pathological lesions on ulna #180 based on x-ray (**Figure 7**). Postmortem erosion is seen in the faded upper left area of the bone mentioned. Additionally there is a hairline crack on the lower half of the shaft. Due to the lack of bony growth, this crack was postmortem. The greatest area of interest is the trauma on the distal end of the shaft. This lesion is radiodense, which means new bone has been laid down since the injury. New bone growth demonstrates that unlike the other two lesions, this one did not occur due to taphonomy. The distal lesion occurred antemortem. Based on the density shown in the radiograph, the posterior side of the injury has the thinnest layer of new bone, while the anterior side has the thickest of the new bony deposits. The posterior cortical bone at the area of injury is equivalent in size to uninjured areas of bone, which will be discussed in a later section. The medullary cavity is fully encapsulated from the outer environment, without antemortem or postmortem breaks.

The distal lesion is definitely a form of paleopathology; it cannot be attributed to taphonomy and the shape of the injury cannot be attributed to normal anatomical variation. Therefore, it can be concluded that ulna #180 is some form of trauma. The next step, (according to Chhem and Brothwell 2008) is to perform a differential diagnosis to narrow down the type of trauma. Based upon the basic fracture classification as discussed in Chapter III, if ulna #180 is a fracture, it is a complete nonunion fracture, as there are no other bones that articulate with it. One possible cause of trauma in ulna #180 is a transverse fracture because the types of forces that cause amputations and transverse fractures are the same. Ulna #180 could also be a comminuted fracture, but as only one portion of the ulna is available, it is difficult to determine whether ulna #180 broke into two pieces, a transverse fracture, or three, a comminuted fracture. Ulna #180 could also be a parry fracture based on the location of the break, as parry fracture are associated with injuries along the midshaft to the distal end of the ulna. The trauma in ulna #180 could have been caused by several different fracture types, as discussed above; however, without further evidence the specific type of fracture to cause the trauma cannot be determined.

Conversely, if ulna #180 is an amputation, it could be one of three specific types of amputations (as previously discussed in Chapter III). If the injury is an amputation, it is most likely dismemberment by natural causes, accidental amputation, or medical amputation. These three types of amputations are the most likely to occur throughout time, regardless of cultural factors. The other two less likely types of amputation are ritual amputation, as cultural context is needed, and amputation caused by warfare, which requires weaponry such as swords, guns and large artillery. Based on the location of the injury in Ulna #180 and the lack of context of the individual, it is unlikely to be these two options.

The cause of the injury is less important than the differential diagnosis. In order to differentiate between nonunion fracture and amputation, a set of diagnostic criteria were selected. To ascertain the variability of either type of injury, data from one known nonunion fracture and four known amputations were collected. These comparative data, in conjunction with criteria collected from paleopathological sources, were utilized to create a list of five major characteristics that differentiated a nonunion fracture from an amputation for further classification of the trauma located on ulna #180.

Figure 7: X-ray of ulna #180. X-ray provided by J. Radovčić (Zagreb). The blue arrows highlight postmortem loss of bone as both are radiolucent and show no new bone growth. The red arrow indicates the major trauma of interest. At this area of injury, the bone is comparatively denser than the postmortem injuries that indicate that new bone has been laid down, demonstrating this trauma occurred antemortem.

Comparative Evidence from the Mütter Museum

In addition to descriptions and images from the literature, physical specimens were observed. The Mütter Museum provided five dry bone specimens for observation: four amputations and one nonunion fracture. Unfortunately, none of the specimens had associated x-rays or CT scans, though one specimen, 1454.50, was partially sectioned. All specimens were obtained during the Civil War era and the specific type of trauma for each specimen is known. While ulna #180 is not likely to be an amputation caused by warfare, there are few amputations available for study. The main goal of this thesis is to determine the difference between a nonunion fracture and an amputation, and if possible further classify what type of fracture or amputation. The specimens provided by the Mütter Museum are the most readily available to help create criteria for the distinction between a nonunion and an amputation. Detailed notes have been made for each specimen and photographs taken for comparison. The evidence provided by the specimens is used in conjunction with the protocols found in the literature to create a set of specific criteria for differentiation between amputation and nonunion fracture. This set of criteria has been utilized to determine the type of trauma found on ulna #180.

1427.52

Specimen 1427.52 **(Figure 8)** is a right tibia and corresponding fibula. Both tibia and fibula show fractures. The fibula is obliquely broken at the midshaft, and the fracture healed, but it has not completely remodeled and did not set properly. The distal portion of the fibula shows signs of severe warping caused by the initial injury and the healing that occurred afterwards. The tibia is the main bone of interest for this specimen as it contains a nonunion fracture. There is some slight postmortem erosion at the proximal end, near the tibial tuberosity and the distal end of the medial malleolus, where the bone chipped off after death. The initial trauma to the tibia is an oblique fracture in the distal third of the bone. The two portions of the bone show signs of healing; however, the tibia never healed properly before death and thus is a nonunion. Eburnation on both parts of the bone can be seen along the fracture line (**Figure 9)**. The two pieces of bone approximate each other, but the bone tissue does not conjoin (**Figure 10**). Both portions of the fractures are open; the medullary cavity is open and accessible through the fractured area.

Figure 8: Anterior view of 1427.52

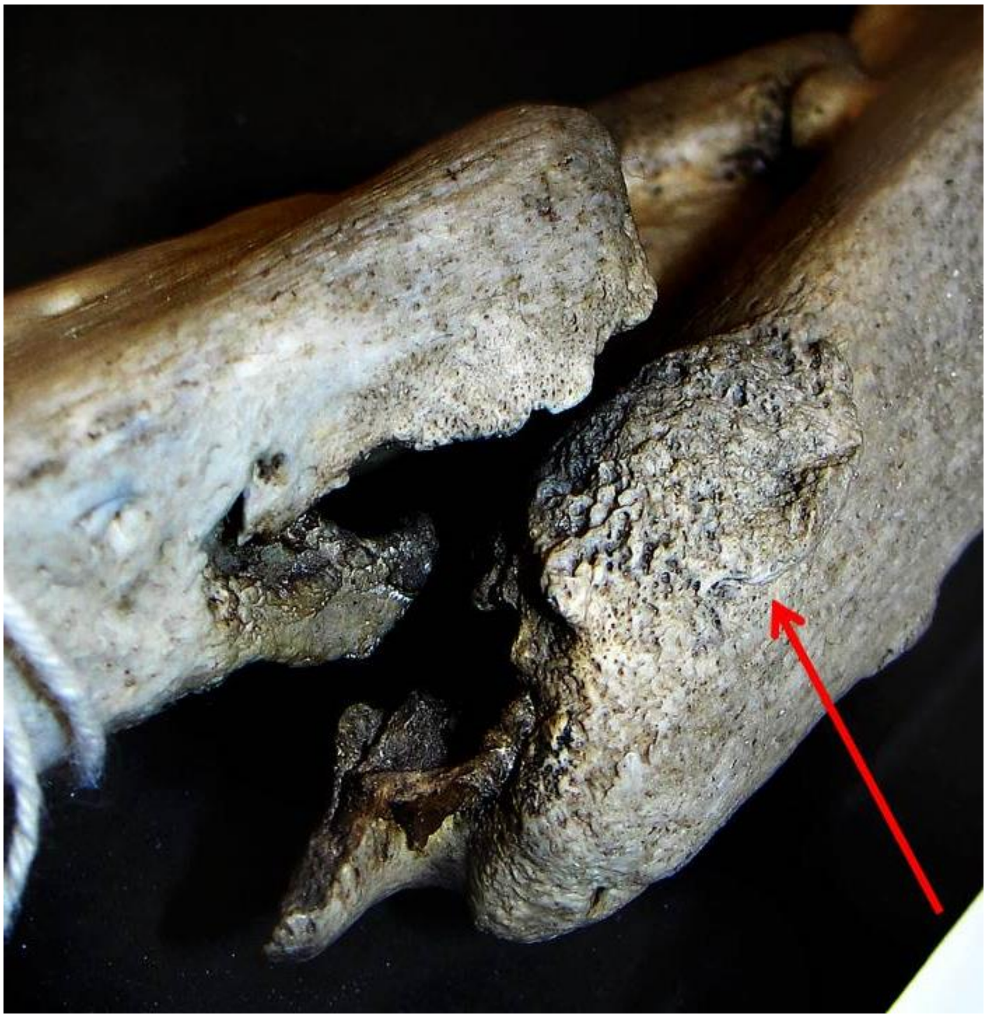

Figure 9: Close up of 1427.52. The right bone fragment has eburnation caused by the left bone fragment. The eburnation has created a different texture to the bone making it distinction from rest of the bone that did not come into contact with left bone fragment. The bony fragments were close enough to knit together; however, they did not.

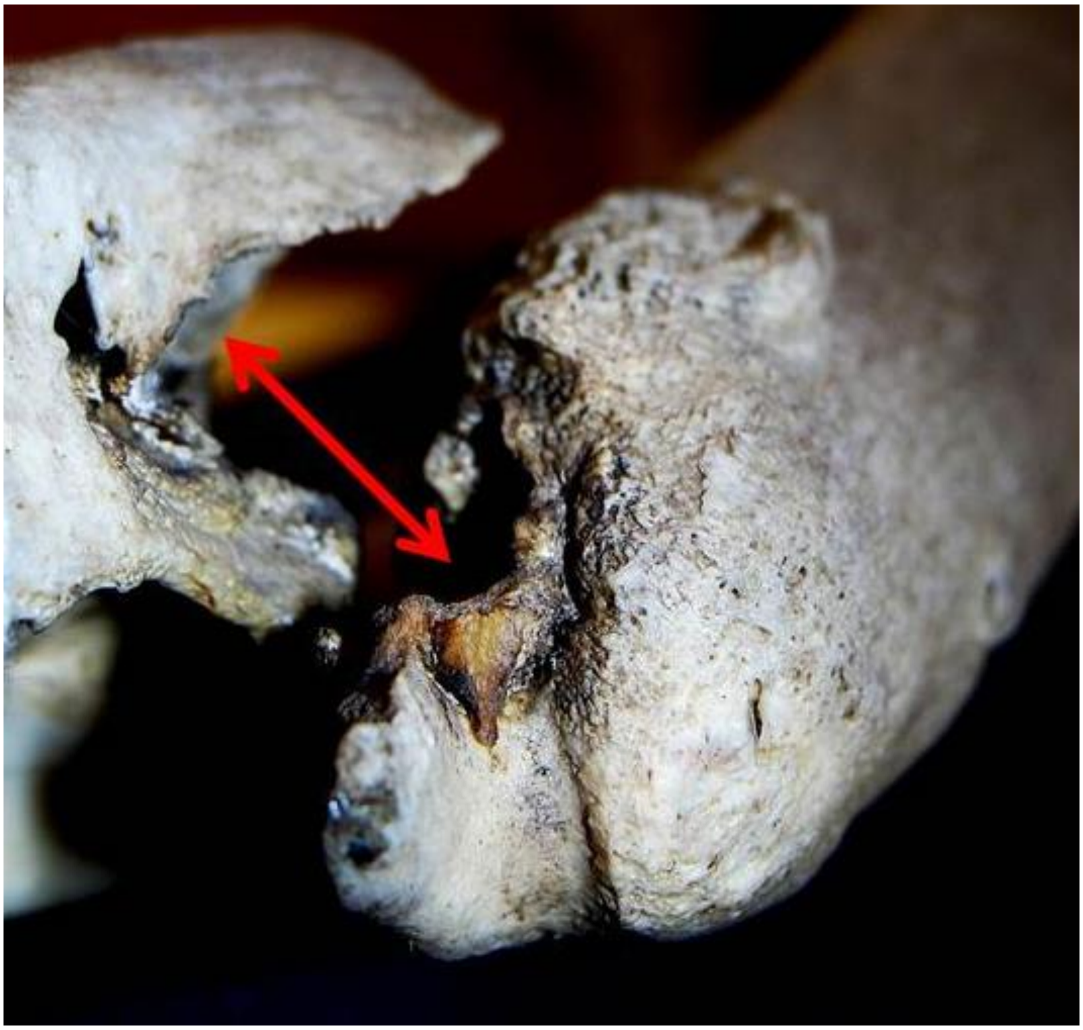

Figure 10: Alternative close up of 1427.52. The medullary cavity is open and exposed at the area of trauma on both bones.

1409.05

Specimen 1409.05 is a left femur (**Figure 12**). The only source of pathology is a trauma close to the midshaft of the bone. This trauma is an amputation and has remodeled since the trauma s occurred. Bony spicules can be seen from the medial area of remodeling; these bony growths may be myositis ossificans (**Figure 11)**. The injury site shows signs of healing, in particular, a very well rounded cap. From a distal view, the bone was in the process of closing the inner medullary cavity, though a small gap remains (**Figure 13**). Based on the physical evidence, a major factor in determining ulna #180's trauma is the openness of the area of trauma, as nonunion fractures have points of access to the medullary cavity.

Figure 11: Close up of the additional bony spicules

Figure 12: Anterior view of 1409.05. Arrow indicates potential myositis ossificans.

Figure 13: Distal end of 1409.05. The rounded end has not healed completely; note the gap at the center.

1268

Specimen 1268 is a right humerus (**Figure 14**). There are several types of pathology to observe on this bone. The pathology of interest is an amputation. Both the distal end of the amputation stump and the humeral head have postmortem erosion (**Figure 15)**. Unlike 1409.05, specimen 1268 did not heal without further complications. The area around the injury are infected, probably osteomyelitis, as observed by the pitting covering the entire bone. The infection affected the remaining bone to the extent that healing making 1268 less useful for comparative purposes, as the bone has become necrotic.

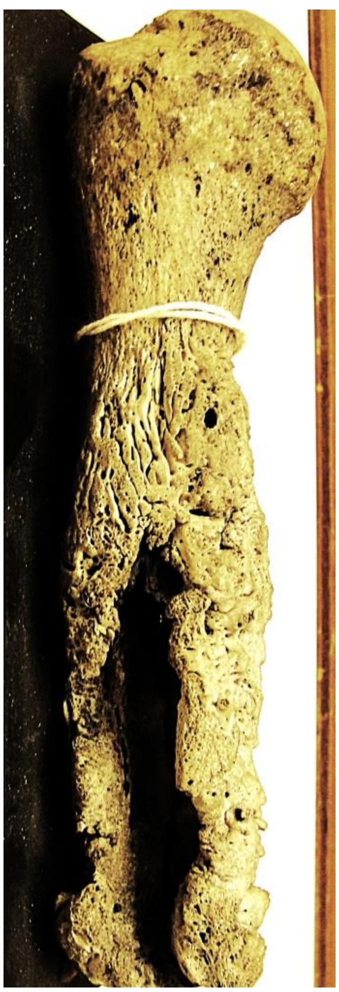

Figure 14: Anterior view of 1268. The amputated bone was severely infected, making less useful for comparative purposes.

Figure 15: Arrow indicates postmortem erosion at humeral head

1454.10

Specimen 1454.10 is an isolated left tibia (**Figure 16**). Only the proximal end of the specimen remains, the rest has been removed by amputation. At the distal end, on the medial side of the tibia there is a cut that extends up through a third of the remaining portion of the shaft. This cut shows signs of healing and may be related to the amputation. This injury shows signs of healing, as both sides of the split fused together after the initial traumatic incident. The amputation also shows signs of healing. Specimen 1454.10 is further along in the healing process than 1409.05; this is evidenced by a completely closed off medullary cavity and the semi-rounded cap that Steinbock (1976) describes as typical for amputations (**Figure 17)**.

Figure 16: Anterior view of 1454.10.
The site of the amputation has a
semi-rounded cap.

Figure 17: Distal end of 1454.10. The traumatic callus
has sealed off the medullary cavity

1454.50

The final specimen is a right tibia and fibula, 1454.50 (**Figure 18)**. Both are amputated at the midshaft. Both bones also have pockmarks on the outer layer of bone, which indicates an infection, most likely periostitis that only affects the cortical bone, on the posterior portions. The tibia has been sectioned in half postmortem and has also been altered with a hinge. This allows the bone to be opened and closed for examination of the interior cavity. Both the fibula and tibia show signs of healing at the areas of injury. The cap on the fibula is completely closed off, while the cap on the tibia amputation has a small hole, which appears to have been caused by the sectioning process (**Figure 19**). The ends of the stumps are not rounded off; instead, the distal end of the fibula curves towards the tibia, and the distal end of the tibia protrudes in the direction of the fibula. It is possible that the two bones were attempting to fuse together, similar to the amputation described by Brothwell and Møller-Christensen (1963a).

When the hinge is opened on the tibia, areas where infection has affected the size and shape of the bone can be seen (**Figure 20**). As there are no x-rays available for the bones from Mütter Museum, the sectioned tibia is the closest comparative evidence of cortical thickness based on the CT scans and x-rays of ulna #180 and other sources in the literature. The upper portions of the sections have no pathology of note. At the midshaft of the bone, periostitis can be seen, as the infection has inflamed the cortical bone. The bony growth at the area of trauma has affected the proportion of cortical and spongy bone (**Figure 21**). The thinnest layer of bone is at the distal end. The cortical bone deposition on both the anterior and posterior side of the bone is a similar proportion in areas of the tibia that have been unaffected by trauma. The major difference is the reduction of cortical bone at the point of trauma.

Figure 18: Anterior view of 1454.50. The bony growth on the fibula and tibia has healed towards each other.

Figure 19: The distal ends of the tibia and fibula of 1454.50 are completely closed. The cap on the tibia has been affected by the sectioning process.

Figure 20: Unaltered sectioned photograph of 1454.50. While not as useful an x-ray or a CT-scan, it still shows some details. The blue arrow indicates the thickening of cortical bone as caused by a bacterial infection. The red arrow indicates the absence of cortical bone at the distal end of the amputation.

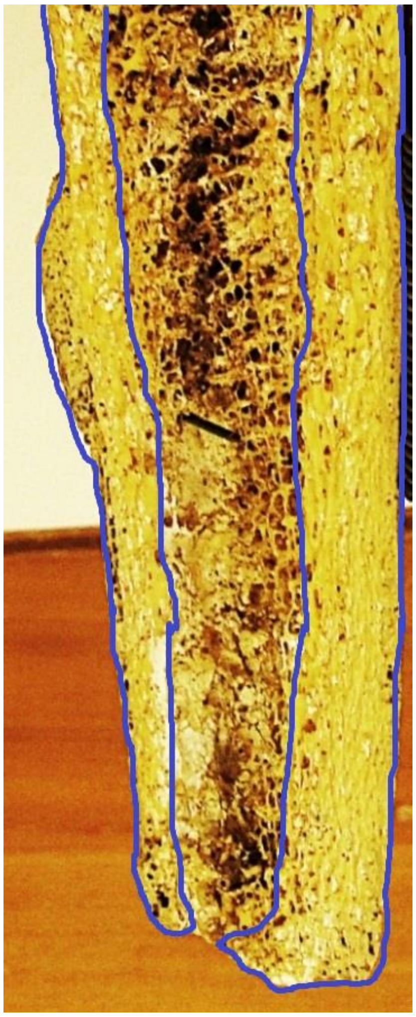

Figure 21: An enhanced photograph of the lateral side of the sectioned tibia. Blue lines surround the cortical bone to help the reader identify the general thickness of cortical bone in areas affected and unaffected by the amputation. At the most distal end (the area that was most affected), the cortical bone is thinner than areas unaffected by trauma. The anterior and posterior sides of the distal ends are relatively comparable to the unaffected bone.

Diagnostic Criteria

Based upon the criteria provided in Chapter IV and the data presented in the previous sections, five characteristics have been selected to differentiate nonunion fractures from amputations.

Medullary cavity

The medullary cavity is the space inside long bones. In amputations, soft spongy bone hardens and recreates the outer shell that was present before the injury (Steinbock 1976). In nonunion fractures, this process could occur, but it is not always the case. Even though the injury has removed the protective exterior layer of cortical bone, the healing process does not create a callus to protect the medullary cavity. Rather the two broken bones work to function as a whole even though they are not attached to one another. They seek to join to the other bone, thus the closure of the medullary cavity is secondary to the connection of the two pieces of bone. A callus formed as the result of a nonunion fracture may not heal to protect the medullary cavity; it may leave patches open and not create a full barrier (**Figure 10**). Conversely, a characteristic of an amputation is a callus forming or fully formed, encapsulating the medullary cavity to restrict access (**Figures 17 and 19**). The figure on the next page illustrates the medullary cavity of ulna #180 (**Figure 22)**. The medullary cavity of ulna #180 is completely encapsulated by cortical bone. This criterion indicates that ulna #180 is an amputation.

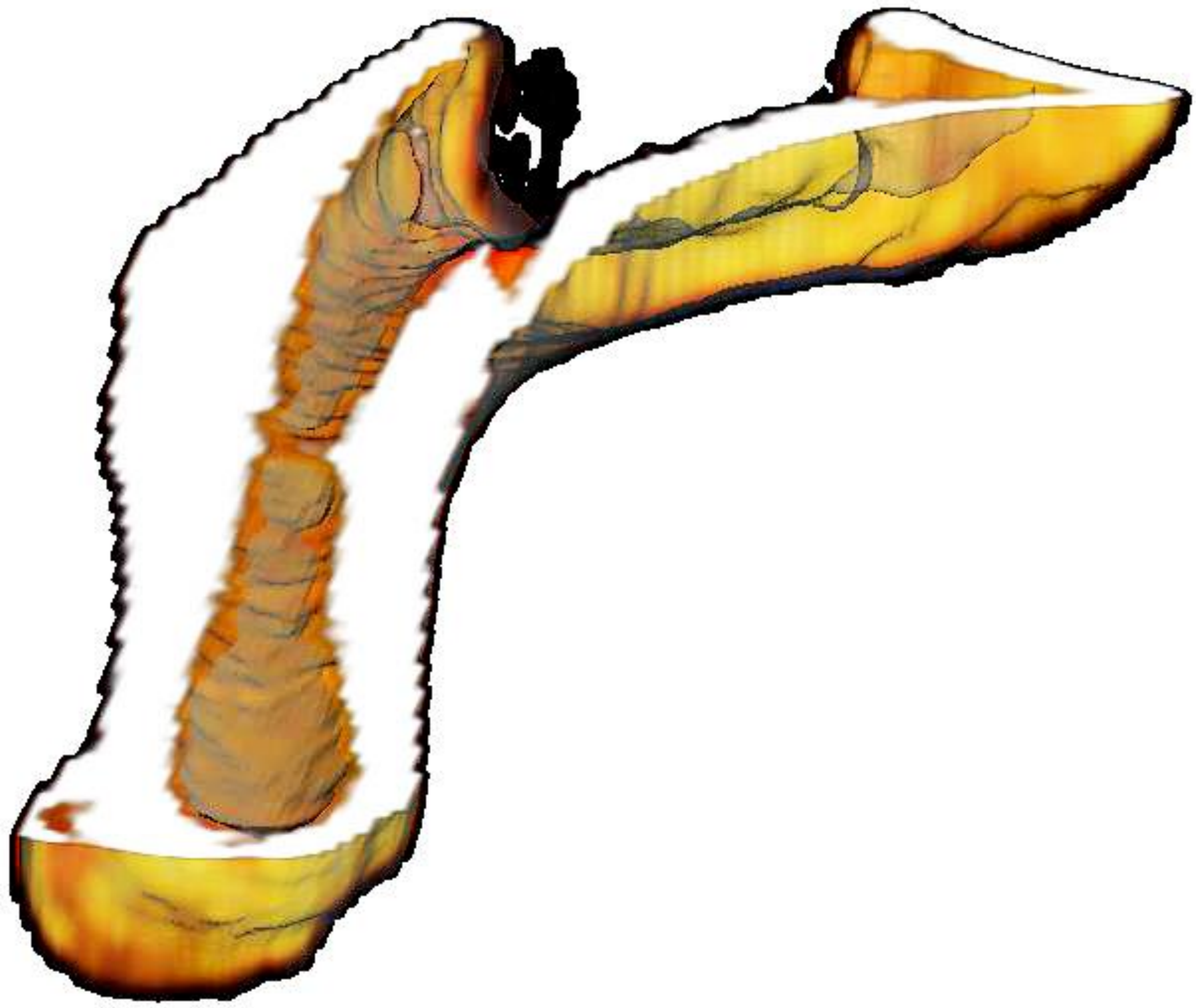

Figure 22: CT scan of ulna #180 (L. Bondioli Rome). The white layer is the cortical layer and the inner orange is the medullary cavity. The distal end of the ulna is surrounded by a layer of cortical bone. The medullary cavity is completely isolated from the external surface.

Presence of eburnation

Eburnation occurs when two bones rub against each other, creating a polished surface at the point where the two bones connect that contrasts with the surrounding unaffected bone. This occurs in nonunion fractures that have attempted to heal together, albeit unsuccessfully (Mora 2006). The broken bones remain close together, and eburnation is likely to occur as seen in specimen 1427.52 (**Figure 9**). Amputations do not have two remaining sections of bone, thus it would be very unlikely for eburnation to occur at the site of trauma (**Figures 11, 16, 18)**. The only way for eburnation in an amputation to occur would be if the adjacent long bone had changed position during trauma, pushing the two bones close together.

Ulna #180 has a slight groove that runs along the medial side of the injury. After the groove indentation, there is a slight tuberosity on the trauma callus, which bulges outwards **(Figure 23)**. These features do not make the trauma callus perfectly rounded; however, there are no portions of the bone that have the polished surface indicative of eburnation **(Figure 9).** This characteristic would indicate ulna #180 is an amputation.

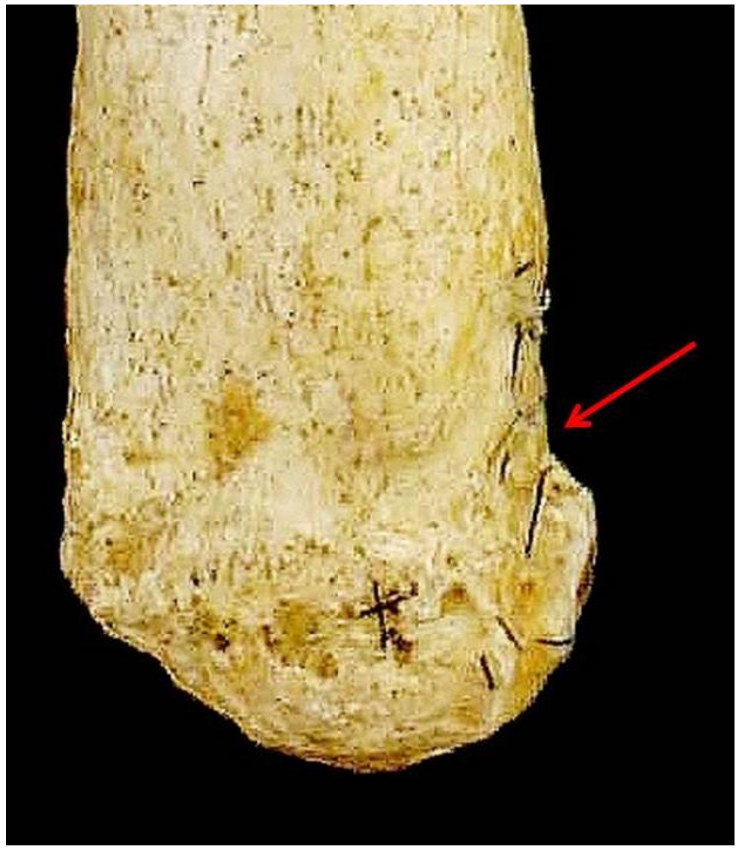

Figure 23: Photograph of the distal end of ulna #180 at the point of trauma (Provided by D. Frayer Lawrence). The red arrow indicates the indentation of the traumatic callus followed by a slight tuberosity on the anterior side. The surface of the traumatic injury has not changed to indicate a hard object had worn it down. It contains no signs of eburnation, which is a characteristic of an amputation.

Smooth bony cap

According to the literature, amputations and nonunion fractures can result in the formation of a bony cap at the site of trauma. Nonunion fractures form a pseudojoint, also known as pseudarthrosis (Aufderheide and Rodriguez-Martin 1998, Buikstra and Ubelaker 1994). The broken bones interlock with one another to recreate the former whole normal bone. There is no standard shape of a pseudojoint (**Figures 2, 5, 8, 24, 25, and 26**). In contrast, amputations have a somewhat standard healing callus. In the observed instances from Mütter Museum samples, with the exception of 1268 that had also been severely infected resulting in necrosis, the callus at the end of the amputations is smooth and oval in shape (**Figures 12, 16, and 17)**. The literature also indicates amputations result in smoothed and rounded callus (Barber 1929, Steinbock 1976). If the traumatic lesion is smooth and rounded, there is a good indication that the trauma is an amputation; however, if the lesion is irregularly shaped it is more likely to be a nonunion fracture. The callus on ulna #180 is smooth; there is a slight tuberosity on the distal end that prevents the cap from being perfectly round (**Figures 7, 22, and 23)**. Based on the bone growth during healing, ulna #180 fits the description of an amputation more than a nonunion fracture.

Additional bone growth

One characteristic that coincides with the smooth rounded cap found in amputations and cortical thickness (discussed in the next section) is the pattern of additional bone growth. The focus of healing in amputations is to create a smooth rounded cap; whereas, with nonunion fractures the goal of healing is to fuse the broken bone together in whichever way possible. Amputations have a uniform shape in comparison to the variable shape of nonunion fractures. In addition to this variable shape, the callus on nonunion fractures will have additional bony growth that extends and expands past the point of initial trauma in the attempt to unite the two bones (**Figures 24, 25, and 26**). The additional bone growth on an amputation tends to be more self-contained **(Figures 17 and 18).** Based on various forms of imaging, ulna #180 corresponds more with the bone growth of amputations than the bone growth of nonunion fractures (**Figures 7, 22, and 23).**

Figure 24: Nonunion fracture of a femur (Ortner 2003: 129). The arrows highlight bone growth that expands and extends away from the point of trauma.

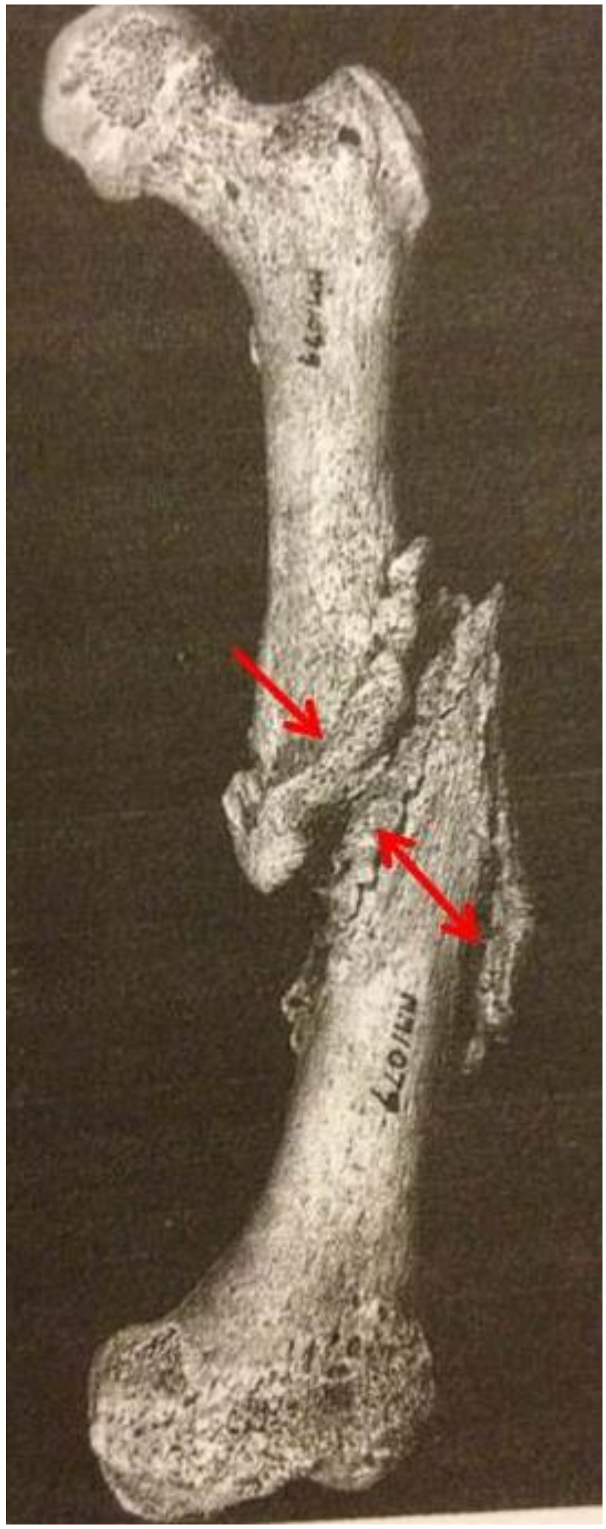

Figure 25: Nonunion fracture of the femur (Aufderheide and Rodriguez-Martin 1998: 21). The arrows highligt the additional bone growth that extends past the point of union in the two broken bones.

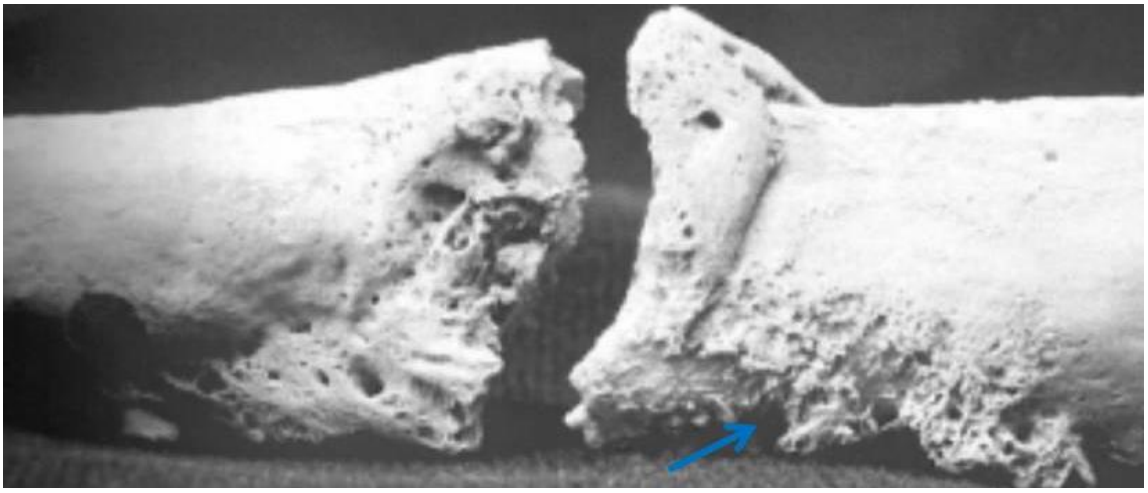

Figure 26: Nonunion fracture (Mann and Hunt 2005:113). Note the two bones form a pseudarthrosis as they correspond with each other at the point of trauma. The blue arrow indicates additional bony growth that extends beyond the initial point of trauma.

Thickness of cortical bone

On radiographs, cortical bone appears with a higher density than the medullary cavity. Based on the radiographs provided below and the sectioned tibia of 1454.50, a difference in cortical thickness between nonunion fractures and amputations can be seen. The healing found in nonunion fractures can be associated with an additional layering of cortical bone. An increase in cortical thickness around the area of trauma would indicate a nonunion fracture (**Figures 27 and 28**). The cortical thickness from sectioned tibia in 1454.50 is thinner at the area of trauma at the distal end but the anterior and posterior section of cortical bone near the trauma is comparable in size to unaffected bone (**Figure 20 and 21)**. A radiograph of a different amputation has equivalent levels of cortical density between the site of amputation and unaltered bone (**Figure 29**). In ulna #180, the cortical bone is thinnest on the anterior side of the injury. The posterior side has the thickest of the new bony deposits, which is comparable in thickness to uninjured areas of bone. Ulna #180 is more similar to the radiograph of the amputation and specimen 1454.50 than it is to the radiograph of the nonunion (**Figures 30 and 31 compared to Figure 29 and Figures 27 and 28)**. Cortical thickness in ulna 180 is comparatively thick when compared to other adult Neandertals from Krapina (**Figure 32).** This characteristic is indicative of an amputation.

Figure 27: Radiograph of a nonunion fracture (Chhem and Brothwell 2008:81). The red arrows indicate areas of bone that demonstrate normal bone growth. The blue arrows highlight areas at the site of the fracture. These points have a high degree of high radiodensity, which indicates a greater proportion of cortical bone.

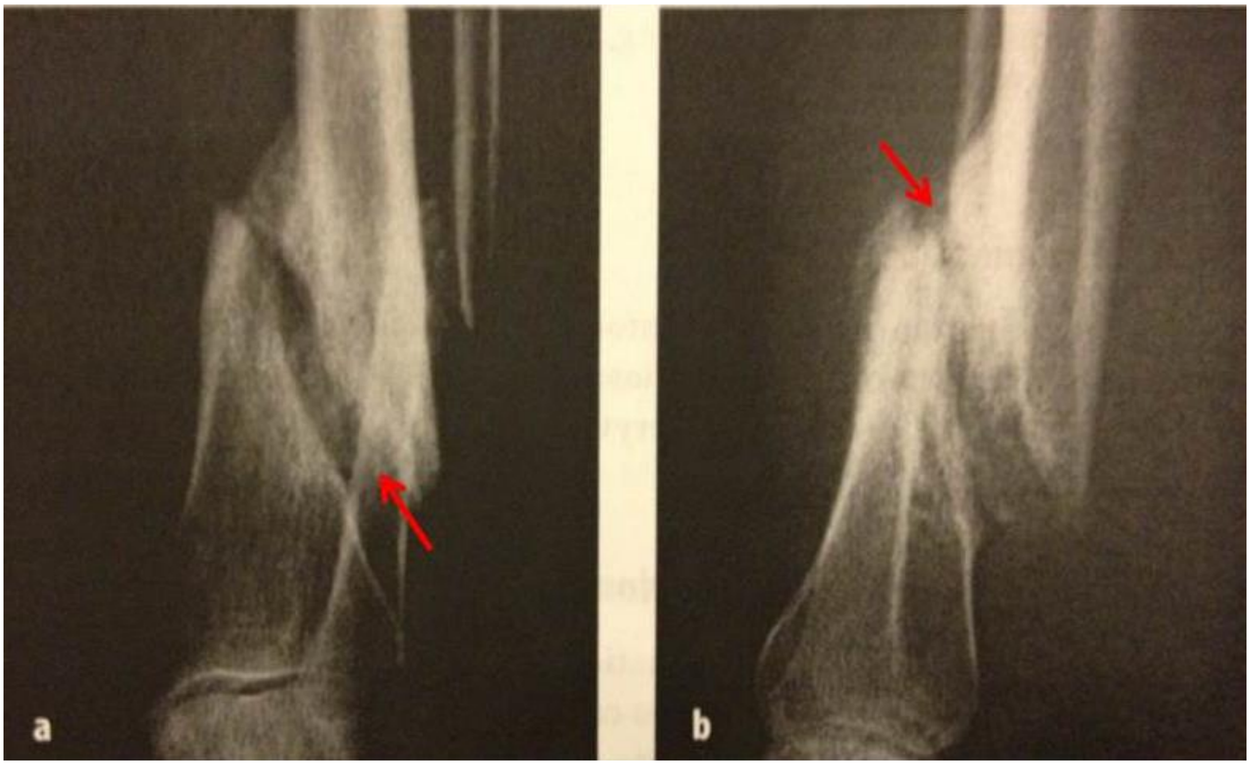

Figure 28: X-ray of a nonunion fracture (Mora *et al.* 2006: 42). Arrows highlight areas of high radiodensity; demonstrating new bone has been laid down in thicker layers than areas unaffected by trauma.

Figure 29: A radiograph of an amputation (Chhem & Brothwell 2008: 83). The blue arrows indicate traumatic areas while the red arrows indicate areas without pathology. The densities of these locations are equivalent, indicating there is no additional cortical thickening at the point of trauma.

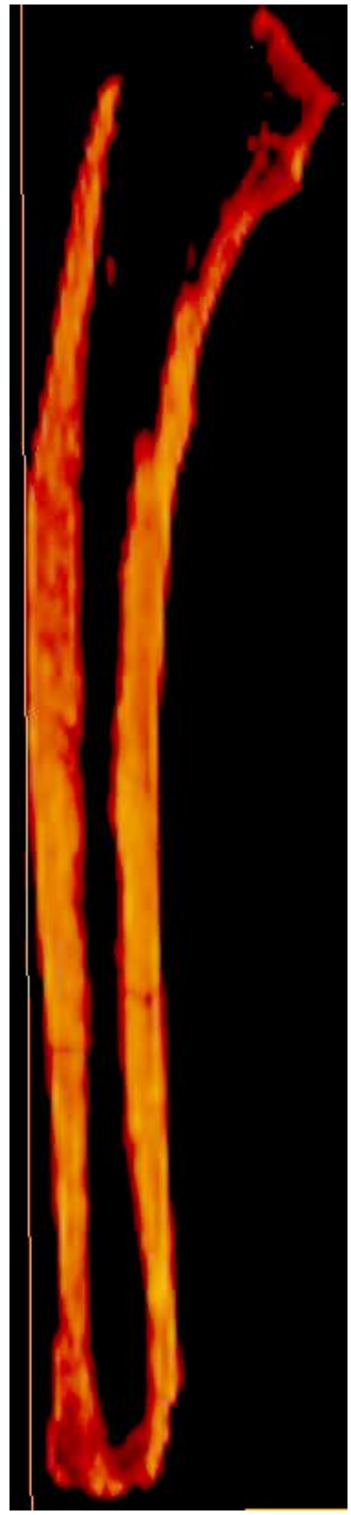

Figure 30: Image of ulna #180 (L. Bondioli Rome). The orange indicates high-density bone, or cortical bone. The cortical bone is thinnest on the anterior side of the injury. The posterior side has the thickest of the new bony deposits and is comparable in thickness to uninjured areas of bone. The ulna was most likely used after the trauma, as the bone does not appear to have significantly atrophied due to disuse. However, more bones related to this individual would be needed to provide more accurate data in regards to atrophy.

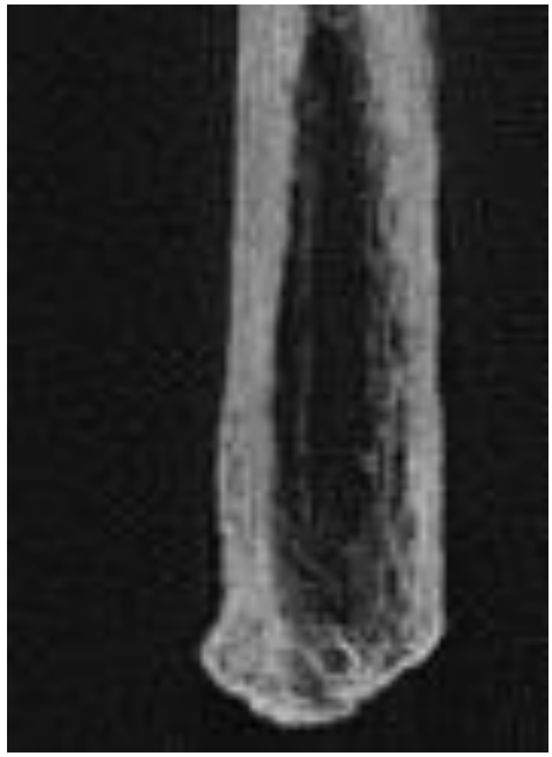

Figure 31: Lateral distal third of ulna #180 (taken from CT scan by J Radovčić Zagreb). Cortical thickness is thinnest at the anterior portion at the site of trauma. The tuberosity on the distal end featured on the posterior side (also see Figure 20) has the thickest cortical bone. The cortical bone at the site of injury is equivalent in thickness to unaffected portions of the bone.

Figure 32: Both ulnas are from adults at the site of Krapina (Croatian Natural History Museum). The ulna on the left is #179 and did not sustain any trauma before death that would alter cortical thickness. The ulna on the right is ulna #180. If ulna #180 was a nonunion fracture it would have a thicker layer of cortical bone at the site of trauma when compared to areas on ulna #180 not injured and to ulna #179. Comparatively, the thickness of ulna #179 is at least as thick as ulna # 180.

Chapter VI: Discussion and Conclusions

This study has determined that the most likely diagnosis of ulna #180 is an amputation. This conclusion is based on five diagnostic criteria that combine characteristics of amputations and nonunion fractures from scientific literature and comparative evidence from the Mütter Museum. Although this study has determined that ulna #180 to be an amputation, previous studies conducted on ulna #180's paleopathology conclude differently.

Dragutin Gorjanovic-Kramberger (1908) initially describes ulna #180 in his article on the skeletal anomalies found at the site. Gorjanovic-Kramberger describes ulna #180 as a break. He notes an irregular swelling near the fracture break and includes an x-ray of ulna #180 to illustrate his point (**Figure 33**). He concludes his description of ulna #180 by noting that the fracture line overlaps the new bony formation (Gorjanovic-Kramberger 1908). In The Krapina Hominids: An Illustrated Catalog of Skeletal Collection, ulna #180 is described as "Right adult shaft from the coronoid process to the midshaft, with only the medial half of the coronoid process. Specimen is pathological; the distal end is the proximal half of a pseudoarthrosis. Maximum length is 144.4 mm." (Radovčić *et al.* 1988: 90)

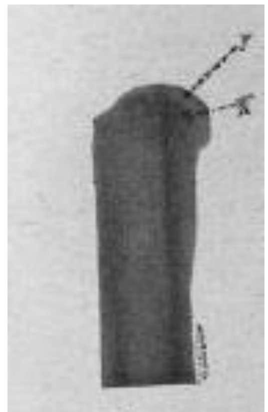

Figure 33: X-ray of Ulna #180 used in initial description (Gorjanovic-Kramberger 1908)

Though first described as a break, descriptions that are more recent are uncertain of the underlying form of trauma. Kricun *et al.* (1999) provide a thorough description of ulna #180.

> "**180** Non-union fracture, or possible amputation, ulna
>
> The distal end of the ulna fragment is round, smooth and shows adjacent sclerosis indicating antemortem non-union or possibly the result of amputation. There is focal periosteal reaction and a smooth irregular surface of the anterior distal aspect of the ulna. The distal cortex is relatively narrow and the medullary space relatively wide…" (Kricun et al 1999: 15)

Gardner and Smith (2006) did a paleopathological inventory of Neandertals at Krapina, which includes a description of ulna #180. They conclude the trauma to ulna #180 is a nonunion transverse fracture, but they also add it might be an amputation. The analysis of the trauma conducted by Gardner and Smith (2006) is inconclusive.

Based on the analysis presented in the Chapter V, ulna #180 has more characteristics indicating an amputation than a nonunion fracture. The criteria behind this conclusion are much more detailed than any of the previous studies (**Table 4)**. A judgment based solely on the presence of pseudarthrosis is not a useful criterion to use, as the healing pattern of nonunion fractures is highly variable. Utilizing multiple measures, methods, and indications for determining between an amputation and a nonunion fracture creates confidence that the correct conclusion has been made. The medullary cavity of ulna #180 is closed, no eburnation is present, it has a smooth cap, there is no additional bone growth that extends past the initial point of trauma, and the cortical thickness is thinner on the anterior side of the injury.

Table 4: Diagnostic Criteria Differentiating Amputations from Nonunion Fractures

Criteria	Amputation	Nonunion Fracture
Medullary Cavity	Closed off with new layer of cortical bone	Variable, potentially closed off or open in areas where the other portion of the break overlaps
Cortical Thickness	Thinner at the area of injury or equivalent in size to areas of the bone unaffected by trauma	Thicker at the area of injury when compared to bone unaffected by trauma
Smooth rounded cap	Present	Highly variable, may be rounded but more likely to be irregularly shaped
Additional bone growth	Callus formation is restricted to the bony cap	Callus formation may extend past the area of injury
Eburnation	Not Present	Variable

It is possible that others have been reluctant to consider ulna #180 to be an amputation because they may consider the possibility of a Neandertal surviving an amputation to be highly unlikely.

However, amputations can be found throughout human existence, potentially including other Neandertals (Trinkaus 1983). Nonhuman cases of amputation prove that an individual can survive with severe trauma without medical care (Bramblett 1968, Kano 1983, Waller and Reynolds 2001). The causes of amputations vary with the historical and cultural context of the individual. Unfortunately, due to the lack of additional evidence which would give more context to ulna #180, the cause of the injury: be it due to natural causes, accidental, medical, ritual, or caused by conflict remains unknown. The individual has survived the injury, meaning this individual was able to cope with the loss of his or her right hand either alone or with the help of others at the community at Krapina.

Suggestions for Further Study

The diagnostic criteria in this study are the preliminary attempt to create a systematic analysis in differenciating between amputations and nonunion fractures. One of the major diffculties in creating diagonositc criteria is the lack of available specimens of both amputations and nonunion fractures. Future studies could exmaine more amputations or nonunion fractures to determine if the criteria is useful. The diagonositic crtieria currently does not provide the users statistical confidence in the diagnosis. Studies that examine cortical thickness in a quantitative way might be one way to create that confidence.

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